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3D Tiles Specification 1.0

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3D Tiles Format Specification

Version 1.0, May 14, 2018

This document describes the specification for 3D Tiles, an open format for streaming massive heterogeneous 3D geospatial datasets.

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Source of the content for this OGC document

The majority of the content in this OGC document is a direct copy of the content contained at https://github.com/AnalyticalGraphicsInc/3d-tiles/tree/1.0 (the `1.0` branch of the `3d-tiles` repo). No normative changes have been made to the content. This OGC document does contain content not contained in the `1.0` branch of the `3d-tiles` repo.

Note: Some elements (such as Vector Data) contained in https://github.com/AnalyticalGraphicsInc/3d-tiles (the 3d-tiles repo) have been removed from the OGC document because they are currently in under development and not a part of this specification. These elements are identified as future work in this OGC document.

Validity of content

The Submission Team has reviewed and certified that the “snapshot” content in this Community Standard is true and accurate.

Future work

The 3D Tiles community anticipates that revisions to this Community Standard will be required to prescribe content appropriate to meet new use cases. These use cases may arise from either (or both) the external user and developer community or from OGC review and comments. Further, future revisions will be driven by any submitted change requests that document community uses cases and requirements.

Additions planned for future inclusion in the 3D Tiles Specification (future work) are described at https://github.com/AnalyticalGraphicsInc/3d-tiles/issues/247.

1 Introduction

In 3D Tiles, a *tileset* is a set of *tiles* organized in a spatial data structure, the *tree*. Each tile has a bounding volume completely enclosing its content. The tree has spatial coherence; the content for child tiles are completely inside the parent's bounding volume. To allow flexibility, the tree can be any spatial data structure with spatial coherence, including k-d trees, quadtrees, octrees, and grids.

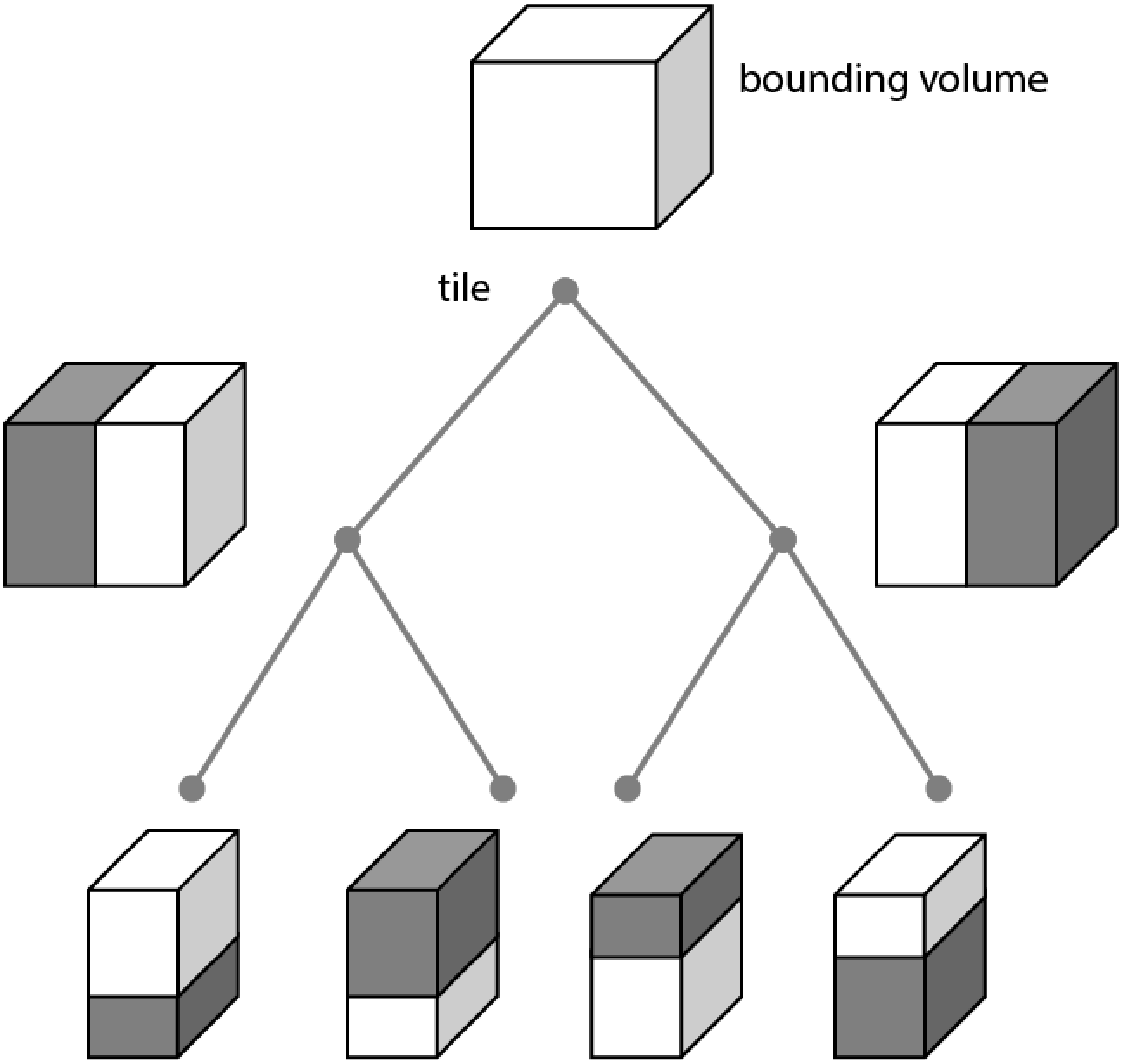


Figure 1: A sample 3D Tiles bounding volume hierarchy

To support tight fitting volumes for a variety of datasets—from regularly divided terrain to cities not aligned with a line of latitude or longitude to arbitrary point clouds—the bounding volume may be an oriented bounding box, a bounding sphere, or a geographic region defined by minimum and maximum latitudes, longitudes, and heights.

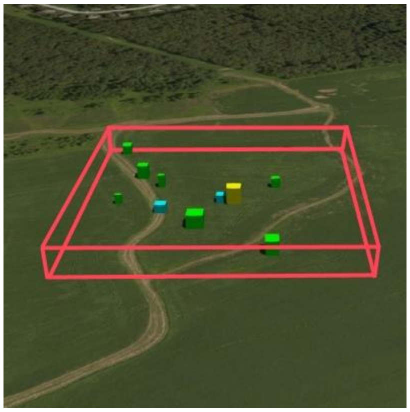


Figure 2: Bounding box

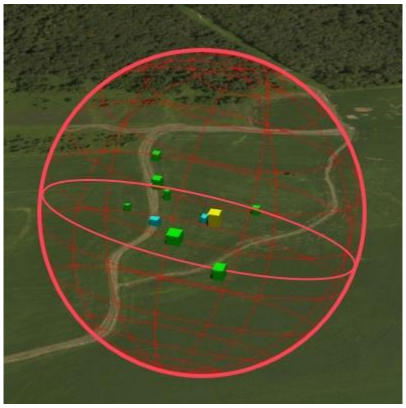


Figure 3: Bounding sphere

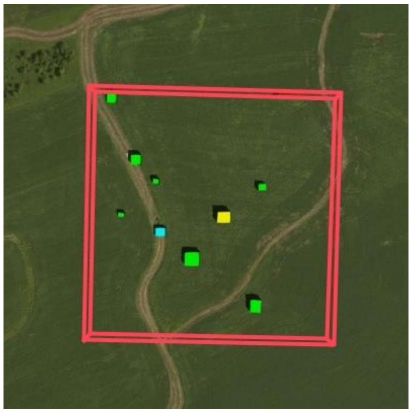


Figure 4: Bounding region

A tile references a *feature* or set of *features*, such as 3D models representing buildings or trees, or points in a point cloud. These features may be batched together into essentially a single feature to reduce client-side load time and rendering draw call overhead.

A 3D tileset consists of at least one tileset JSON file specifying the metadata and the tree of tiles, as well as any referenced tile content files which may be any valid tile format, defined in JSON as described below.

Optionally, a *3D Tile Style* may be applied to a tileset.

1.1 File extensions and MIME types

- Tileset files use the `.json` extension and the `application/json` MIME type.
- Tile content files use the file type and MIME format specific to their tile format specification.
- Tileset style files use the `.json` extension and the `application/json` MIME type.

Explicit file extensions are optional. Valid implementations may ignore it and identify a content's format by the `magic` field in its header.

1.2 JSON encoding

3D Tiles has the following restrictions on JSON formatting and encoding.

1. JSON must use UTF-8 encoding without BOM.
2. All strings defined in this spec (properties names, enums) use only ASCII charset and must be written as plain text.
3. Names (keys) within JSON objects must be unique, i.e., duplicate keys aren't allowed.

1.3 URIs

3D Tiles uses URIs to reference tile content. These URIs may point to relative external references (RFC3986) or be data URIs that embed resources in the JSON. Embedded resources use the "data" URI scheme (RFC2397).

When the URI is relative, its base is always relative to the referring tileset JSON file.

Client implementations are required to support relative external references and embedded resources. Optionally, client implementations may support other schemes (such as `http://`). All URIs must be valid and resolvable.

1.4 Units

The unit for all linear distances is meters.

All angles are in radians.

1.5 Coordinate reference system (CRS)

3D Tiles uses a right-handed Cartesian coordinate system; that is, the cross product of *x* and *y* yields *z*. 3D Tiles defines the *z* axis as up for local Cartesian coordinate systems. A tileset's global coordinate system will often be in a WGS 84 earth-centered, earth-fixed (ECEF) reference frame, but it doesn't have to be, e.g., a power plant may be defined fully in its local coordinate system for use with a modeling tool without a geospatial context.

An additional tile transform may be applied to transform a tile's local coordinate system to the parent tile's coordinate system.

The region bounding volume specifies bounds using a geographic coordinate system (latitude, longitude, height), specifically EPSG 4326.

1.5.1 glTF

Some tile content types such as Batched 3D Model and Instanced 3D Model embed glTF. The glTF specification defines a right-handed coordinate system with the *y* axis as up.

1.5.1.1 *y*-up to *z*-up transform

For consistency with the *z*-up coordinate system of 3D Tiles, glTFs must be transformed from *y*-up to *z*-up at runtime. This is done by rotating the model about the *x*-axis by π/2 radians. Equivalently, apply the following matrix transform (shown here as row-major):

```
[
1.0, 0.0,  0.0, 0.0,
0.0, 0.0, -1.0, 0.0,
0.0, 1.0,  0.0, 0.0,
0.0, 0.0,  0.0, 1.0
]
```

1.5.1.2 Order of transformations

Note that glTF defines its own node hierarchy, where each node has a transform. These transforms are applied before the coordinate system transform is applied. More broadly the order of transformations is:

1. glTF node hierarchy tranformations
2. glTF *y*-up to *z*-up transform
3. Any tile format specific transforms.
   - Batched 3D Model Feature Table may define `RTC_CENTER` which is used to translate model vertices.
   - Instanced 3D Model Feature Table defines per-instance position, normals, and scales. These are used to create per-instance 4x4 affine transform matrices that are applied to each instance.
4. Tile transform

Implementation note: when working with source data that is inherently *z*-up, such as data in WGS 84 coordinates or in a local *z*-up coordinate system, a common workflow is: * Mesh data, including positions and normals, are not modified - they remain *z*-up. * The root node matrix specifies a column-major *z*-up to *y*-up transform. This transforms the source data into a *y*-up coordinate system as required by glTF. * At runtime the glTF is transformed back from *y*-up to *z*-up with the matrix above. Effectively the transforms cancel out.

Example glTF root node:

```
"nodes": [
 {
   "matrix": [1,0,0,0,0,0,-1,0,0,1,0,0,0,0,0,1],
   "mesh": 0,
   "name": "rootNode"
 }
]
```

1.6 Concepts

1.6.1 Tiles

Tiles consist of metadata used to render the tile, content, and any children tiles.

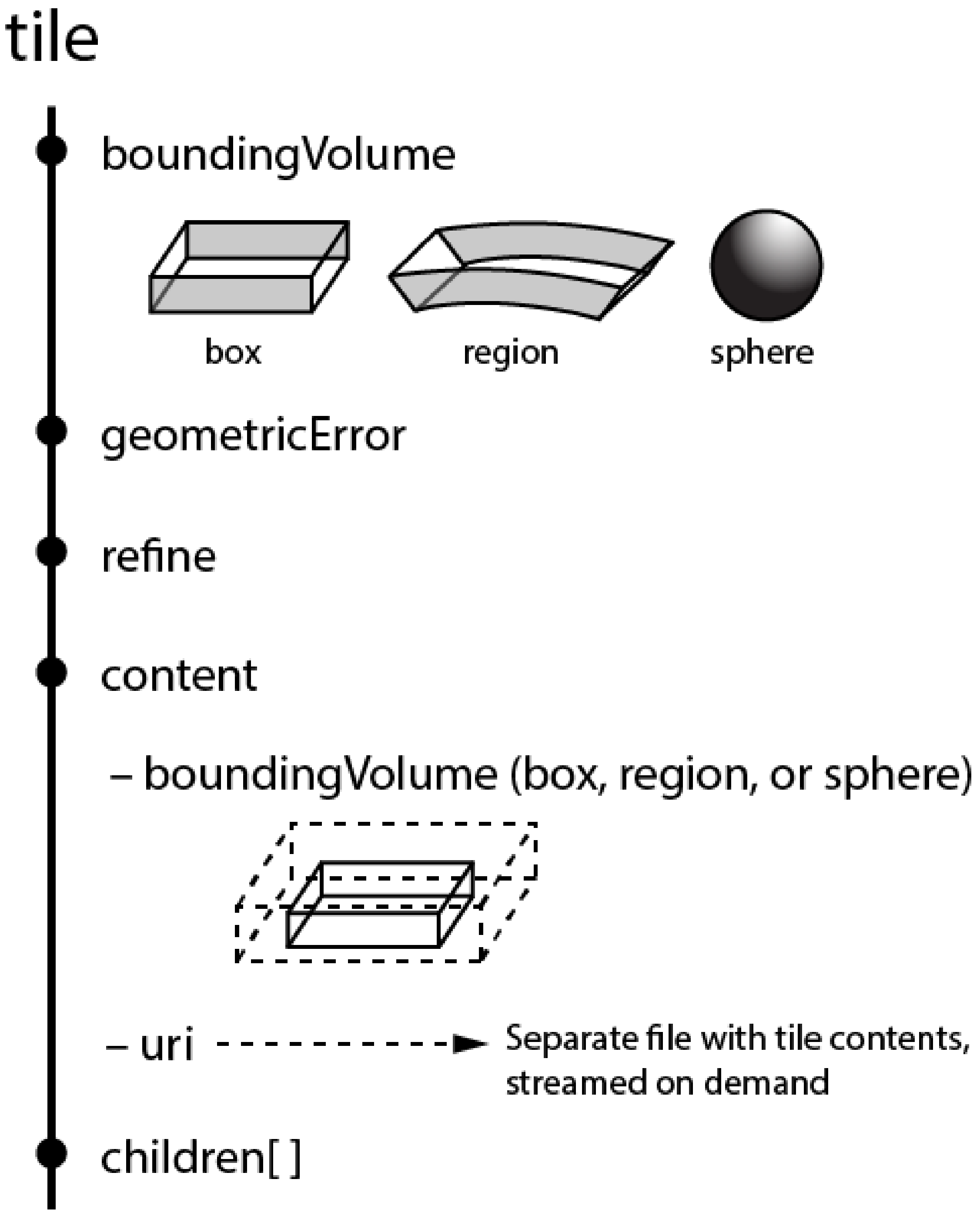

tile
boundingVolume
box
region
sphere
geometricError
refine
content
– boundingVolume (box, region, or sphere)
– uri
Separate file with tile contents, streamed on demand
children[ ]

Figure 5: A representation of tile properties

The following example shows one non-leaf tile.

```
{
  "boundingVolume": {
    "region": [
      -1.2419052957251926,
      0.7395016240301894,
      -1.2415404171917719,
      0.7396563300150859,
      0,
      20.4
    ]
  },
  "geometricError": 43.88464075650763,
  "refine" : "ADD",
  "content": {
    "boundingVolume": {
      "region": [
        -1.2418882438584018,
        0.7395016240301894,
        -1.2415422846940714,
        0.7396461198389616,
        0,
        19.4
      ]
    },
    "uri": "2/0/0.b3dm"
  },
  "children": [...]
}
```

The `boundingVolume` defines a volume enclosing the tile content, and is used to determine which tiles to render at runtime. The above example uses a `region` volume, but other bounding volumes, such as `box` or `sphere`, may be used.

The `geometricError` property is a nonnegative number that defines the error, in meters, introduced if this tile is rendered and its children are not. At runtime, the geometric error is used to compute *Screen-Space Error* (SSE), i.e., the error measured in pixels. The SSE determines *Hierarchical Level of Detail* (HLOD) refinement, i.e., if a tile is sufficiently detailed for the current view or if its children should be considered, see Geometric error.

The optional `viewerRequestVolume` property (not shown above) defines a volume, using the same schema as `boundingVolume`, that the viewer must be inside of before the tile's content will be requested and before the tile will be refined based on `geometricError`. See the Viewer request volume section.

The `refine` property is a string that is either `"REPLACE"` for replacement refinement or `"ADD"` for additive refinement, see Refinement. It is required for the root tile of a tileset; it is optional for all other tiles. A tileset can use any combination of additive and replacement refinement. When the `refine` property is omitted, it is inherited from the parent tile.

The `content` property is an object that contains metadata about the tile's content and a link to the content. `content.uri` is a uri that points to the tile's content.

The uri can be another tileset JSON to create a tileset of tilesets. See External tilesets.

A file extension is not required for `content.uri`. A content's tile format can be identified by the `magic` field in its header, or else as an external tileset if the content is JSON.

The `content.boundingVolume` property defines an optional bounding volume similar to the top-level `boundingVolume` property. But unlike the top-level `boundingVolume` property, `content.boundingVolume` is a tightly fit bounding volume enclosing just the tile's content. `boundingVolume` provides spatial coherence and `content.boundingVolume` enables tight view frustum culling. When it is not defined, the tile's bounding volume is still used for culling (see *Grids*).

The screenshot below shows the bounding volumes for the root tile for Canary Wharf. `boundingVolume`, shown in red, encloses the entire area of the tileset; `content.boundingVolume` shown in blue, encloses just the four features (models) in the root tile.

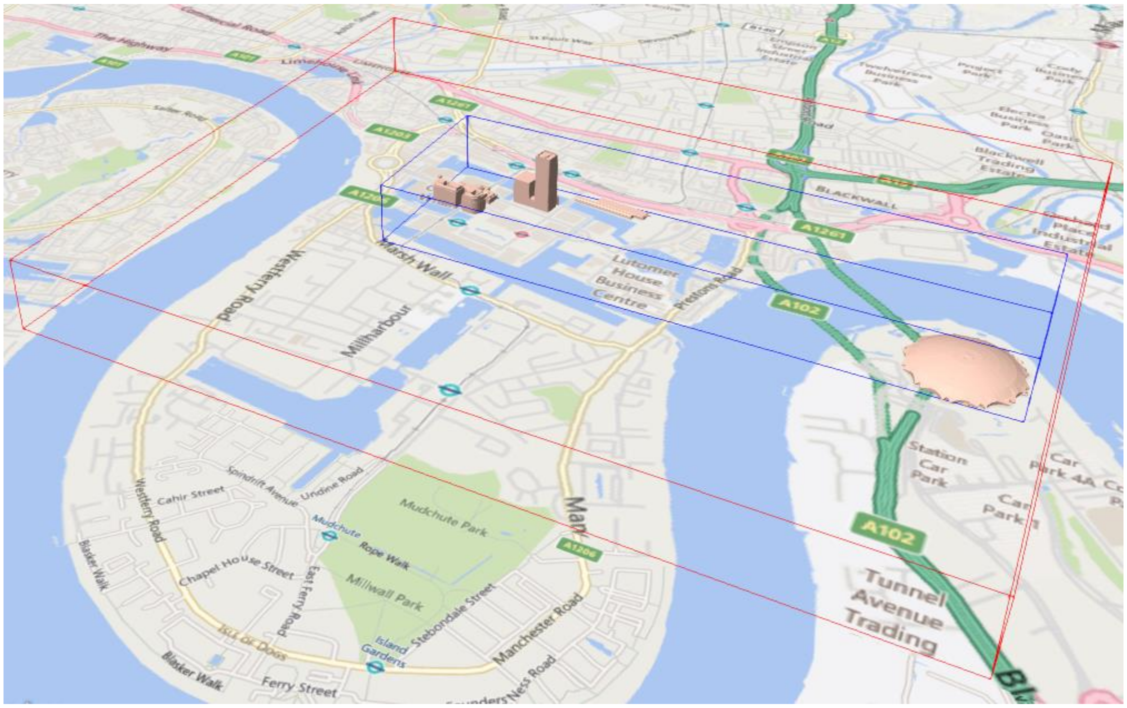


Figure 6: A debug view of bounding volumes for Canary Wharf, including a tile bounding volume drawn in red and a content bounding volume drawn in blue.

The optional `transform` property (not shown above) defines a 4x4 affine transformation matrix that transforms the tile's `content`, `boundingVolume`, and `viewerRequestVolume` as described in the *Tile transform* section.

The `children` property is an array of objects that define child tiles. See the *Tileset JSON* section below.

1.6.2 Bounding volumes

Bounding volume objects are used to define an enclosing volume, and must specify exactly one of the following properties.

1.6.2.1 Region

The `boundingVolume.region` property is an array of six numbers that define the bounding geographic region with latitude, longitude, and height coordinates with the order `[west, south, east, north, minimum height, maximum height]`. Latitudes and longitudes are in the WGS 84 datum as defined in EPSG 4326 and are in radians. Heights are in meters above (or below) the WGS 84 ellipsoid.

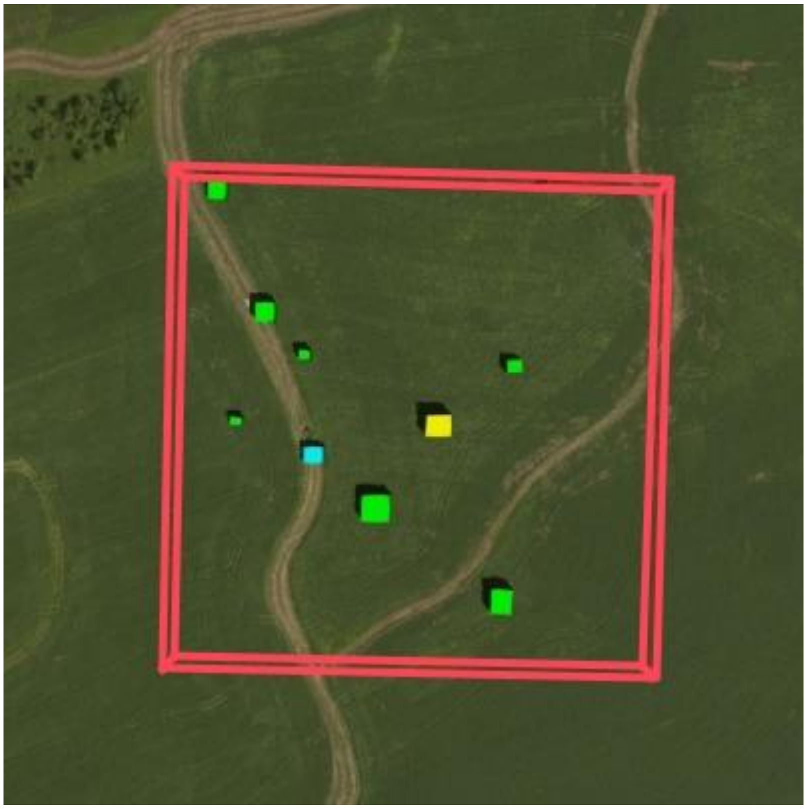


Figure 7: Bounding region

Bounding Region

```
"boundingVolume": {
  "region": [
    -1.3197004795898053,
    0.6988582109,
    -1.3196595204101946,
    0.6988897891,
    0,
    20
  ]
}
```

1.6.2.2 Box

The boundingVolume.box property is an array of 12 numbers that define an oriented bounding box in a right-handed 3-axis (x, y, z) Cartesian coordinate system where the *z*-axis is up. The first three elements define the x, y, and z values for the center of the box. The next three elements (with indices 3, 4, and 5) define the *x*-axis direction and half-length. The next three elements (indices 6, 7, and 8) define the *y*-axis direction and half-length. The last three elements (indices 9, 10, and 11) define the *z*-axis direction and half-length.

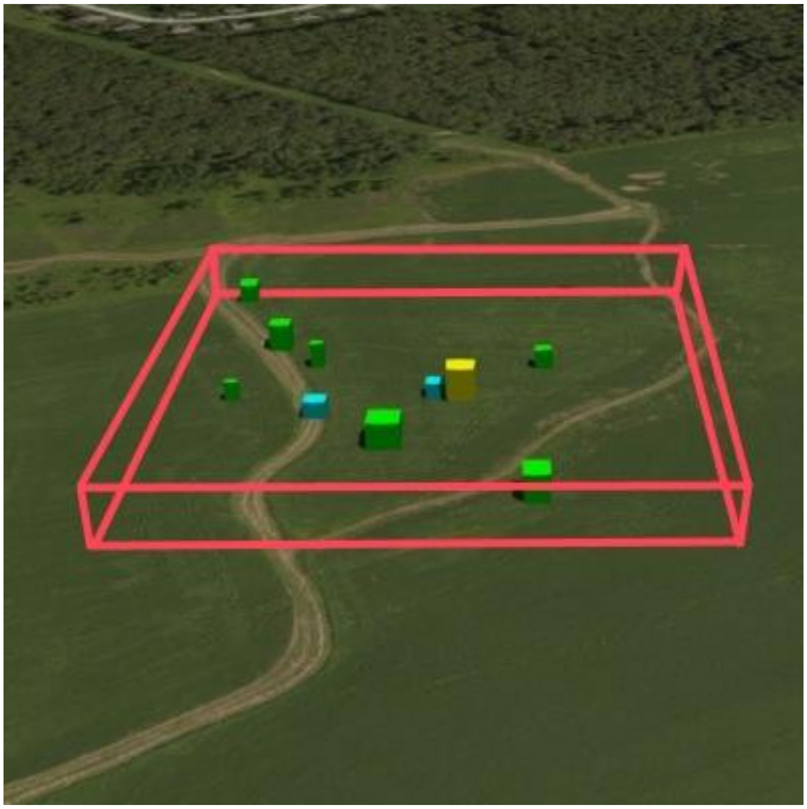


Figure 8; Bounding box

Bounding Box

```
"boundingVolume": {
  "box": [
    0,   0,   10,
    100, 0,   0,
    0,   100, 0,
    0,   0,   10
  ]
}
```

1.6.2.3 Sphere

The boundingVolume.sphere property is an array of four numbers that define a bounding sphere. The first three elements define the x, y, and z values for the center of the sphere in a right-handed 3-axis (x, y, z) Cartesian coordinate system where the *z*-axis is up. The last element (with index 3) defines the radius in meters.

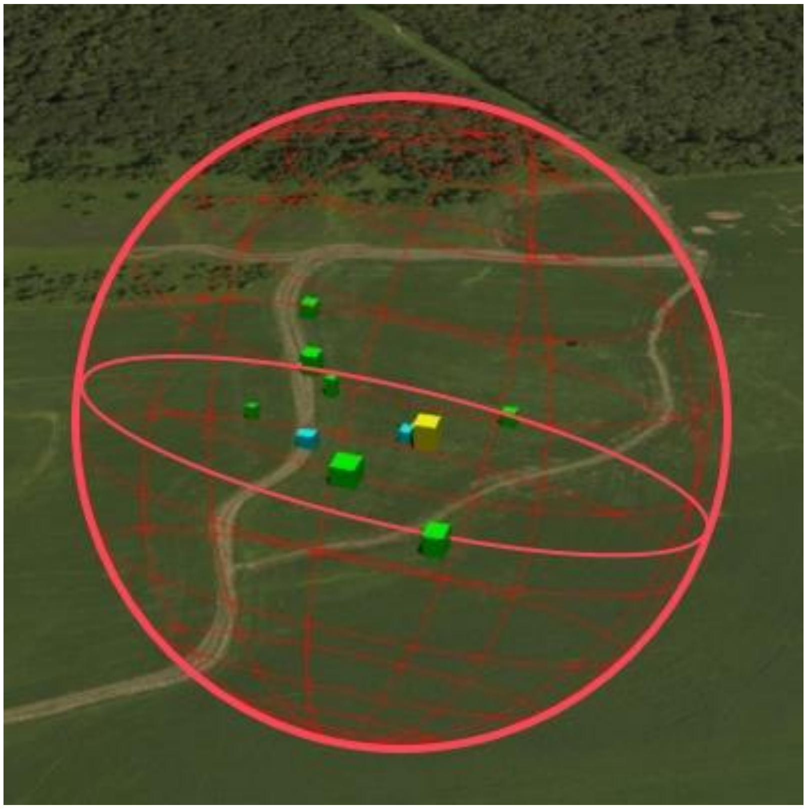


Figure 9: Bounding sphere

Bounding Sphere

```
"boundingVolume": {
  "sphere": [
    0,
    0,
    10,
    141.4214
  ]
}
```

1.6.3 Tile transform

To support local coordinate systems—e.g., so a building tileset inside a city tileset can be defined in its own coordinate system, and a point cloud tileset inside the building could, again, be defined in its own coordinate system—each tile has an optional `transform` property.

The `transform` property is a 4x4 affine transformation matrix, stored in column-major order, that transforms from the tile's local coordinate system to the parent tile's coordinate system—or the tileset's coordinate system in the case of the root tile.

The `transform` property applies to

- `tile.content`
- Each feature's position.
- Each feature's normal should be transformed by the top-left 3x3 matrix of the inverse-transpose of `transform` to account for correct vector transforms when scale is used. * `content.boundingVolume`, except when `content.boundingVolume.region` is defined, which is explicitly in EPSG:4326 coordinates.
- `tile.boundingVolume`, except when `tile.boundingVolume.region` is defined, which is explicitly in EPSG:4326 coordinates.
- `tile.viewerRequestVolume`, except when `tile.viewerRequestVolume.region` is defined, which is explicitly in EPSG:4326 coordinates.

The `transform` property does not apply to `geometricError`—i.e., the scale defined by `transform` does not scale the geometric error—the geometric error is always defined in meters.

When `transform` is not defined, it defaults to the identity matrix:

```
[
1.0, 0.0, 0.0, 0.0,
0.0, 1.0, 0.0, 0.0,
0.0, 0.0, 1.0, 0.0,
0.0, 0.0, 0.0, 1.0
]
```

The transformation from each tile's local coordinate to the tileset's global coordinate system is computed by a top-down traversal of the tileset and by post-multiplying a child's `transform` with its parent's `transform` like a traditional scene graph or node hierarchy in computer graphics.

For an example of the computed transforms (`transformToRoot` in the code above) for a tileset, consider:

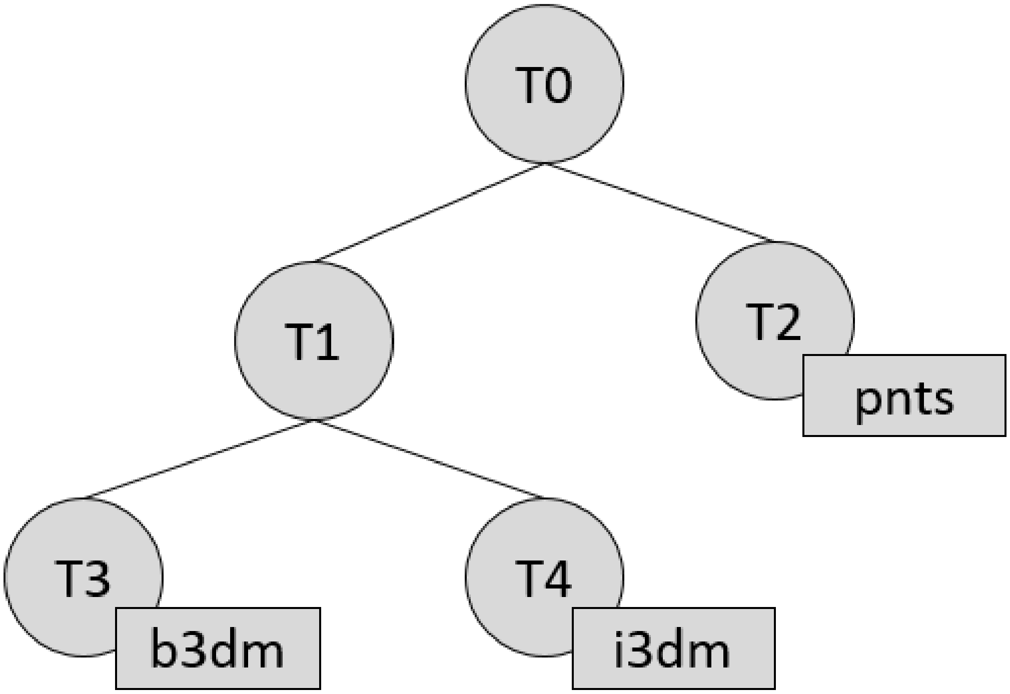


Figure 10: A sample tree of tile with transforms.

The computed transform for each tile is:

`TO`: `[T0]`

`T1`: `[T0][T1]`

`T2`: `[T0][T2]`

`T3`: `[T0][T1][T3]`

`T4`: `[T0][T1][T4]`

The positions and normals in a tile's content may also have tile-specific transformations applied to them *before* the tile's `transform` (before indicates post-multiplying for affine transformations). Some examples are:

- `b3dm` and `i3dm` tiles embed glTF, which defines its own node hierarchy and coordinate system. `tile.transform` is applied after these transforms are resolved. See *coordinate reference system*.

- `i3dm`'s Feature Table defines per-instance position, normals, and scales. These are used to create per-instance 4x4 affine transform matrices that are applied to each instance before `tile.transform`.

- Compressed attributes, such as `POSITION_QUANTIZED` in the Feature Tables for `i3dm` and `pnts`, and `NORMAL_OCT16P` in `pnts` should be decompressed before any other transforms.

Therefore, the full computed transforms for the above example are:

T0: [T0]

T1: [T0][T1]

T2: [T0][T2][pnts-specific transform, including RTC_CENTER (if defined)]

T3: [T0][T1][T3][b3dm-specific transform, including RTC_CENTER (if defined), coordinate system transform, and glTF node hierarchy] * T4: [T0][T1][T4][i3dm-specific transform, including per-instance transform, coordinate system transform, and glTF node hierarchy]

1.6.4 Viewer request volume

A tile's viewerRequestVolume can be used for combining heterogeneous datasets, and can be combined with *external tilesets*.

The following example has a building in a b3dm tile and a point cloud inside the building in a pnts tile. The point cloud tile's boundingVolume is a sphere with a radius of 1.25. It also has a larger sphere with a radius of 15 for the viewerRequestVolume. Since the geometricError is zero, the point cloud tile's content is always rendered (and initially requested) when the viewer is inside the large sphere defined by viewerRequestVolume.

```
{
  "children": [{
    "transform": [
      4.843178171884396,   1.2424271388626869, 0,                  0,
      -0.7993325488216595,  3.1159251367235608, 3.8278032889280675, 0,
      0.9511533376784163, -3.7077466670407433, 3.2168186118075526, 0,
      1215001.7612985559, -4736269.697480114,  4081650.708604793,  1
    ],
    "boundingVolume": {
      "box": [
        0,     0,    6.701,
        3.738, 0,    0,
        0,     3.72, 0,
        0,     0,    13.402
      ]
    },
    "geometricError": 32,
    "content": {
      "uri": "building.b3dm"
    }
  }, {
    "transform": [
      0.968635634376879,    0.24848542777253732, 0,                  0,
      -0.15986650990768783,  0.6231850279035362,  0.7655606573007809, 0,
      0.19023066741520941, -0.7415493329385225,  0.6433637229384295, 0,
      1215002.0371330238,  -4736270.772726648,   4081651.6414821907, 1
    ],
    "viewerRequestVolume": {
      "sphere": [0, 0, 0, 15]
    },
    "boundingVolume": {
      "sphere": [0, 0, 0, 1.25]
    },
    "geometricError": 0,
    "content": {
      "uri": "points.pnts"
    }
  }]
}
```

1.6.5 Refinement

Refinement determines how a parent tile renders when its children are selected to be rendered. Permitted refinement types are replacement (`"REPLACE"`) and additive (`"ADD"`). A tileset can use replacement refinement exclusively, additive refinement exclusively, or any combination of additive and replacement refinement. A refinement type is required for the root tile of a tileset; it is optional for all other tiles. When omitted, a tile inherits the refinement type of its parent.

1.6.5.1 Replacement

If a tile uses replacement refinement, when refined it renders its children in place of itself.

Parent Tile	Refined

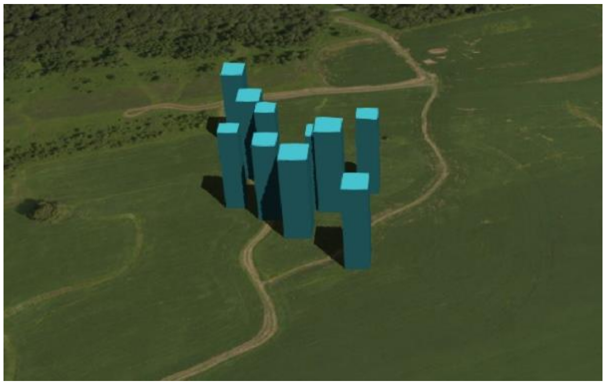
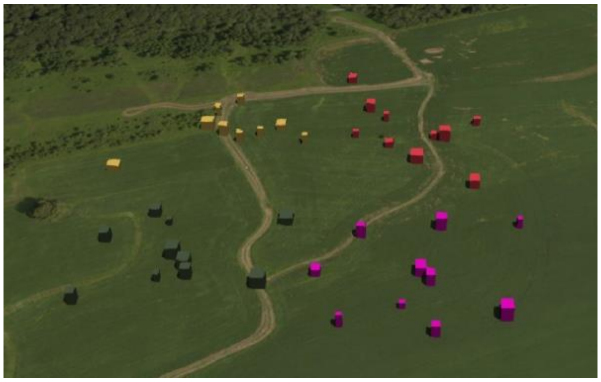

	

Figure 11: A parent tile with replacement refinement	*Figure 12: A refined child tile of a tile with replacement refinement*

1.6.5.2 Additive

If a tile uses additive refinement, when refined it renders itself and its children simultaneously.

Parent Tile	Refined

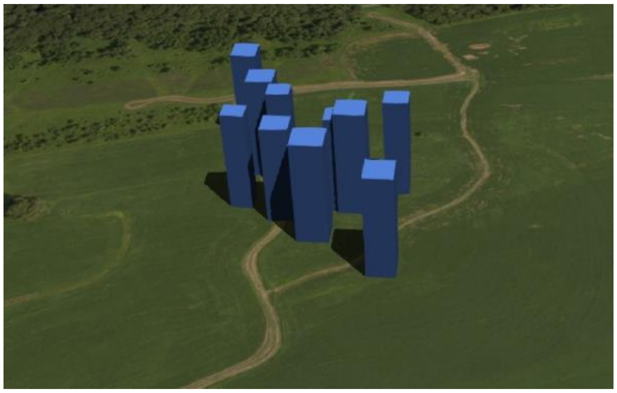


Figure 13: A parent tile with additive refinement

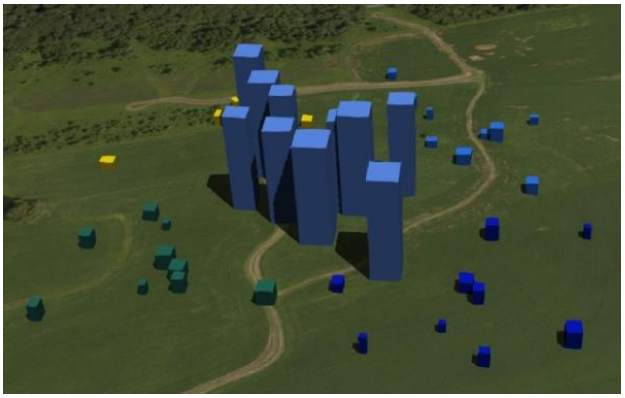


Figure 14: A refined child tile of a tile with additive refinement

1.7 Tileset JSON

3D Tiles use one main tileset JSON file as the entry point to define a tileset. Both entry and external tileset JSON files are not required to follow a specific naming convention.

Here is a subset of the tileset JSON used for Canary Wharf (also see the complete file, tileset.json):

```
{
  "asset" : {
    "version": "1.0",
    "tilesetVersion": "e575c6f1-a45b-420a-b172-6449fa6e0a59",
  },
  "properties": {
    "Height": {
      "minimum": 1,
      "maximum": 241.6
    }
  },
  "geometricError": 494.50961650991815,
  "root": {
    "boundingVolume": {
      "region": [
        -0.0005682966577418737,
        0.8987233516605286,
        0.00011646582098558159,
        0.8990603398325034,
        0,
        241.6
      ]
    },
    "geometricError": 268.37878244706053,
    "refine": "ADD",
    "content": {
      "uri": "0/0/0.b3dm",
      "boundingVolume": {
        "region": [
          -0.0004001690908972599,
          0.8988700116775743,
          0.00010096729722787196,
          0.8989625664878067,
          0,
          241.6
        ]
      }
    },
    "children": [..]
  }
}
```

The top-level object in the tileset JSON has four properties: `asset`, `properties`, `geometricError`, and `root`.

`asset` is an object containing properties with metadata about the entire tileset. The `asset.version` property is a string that defines the 3D Tiles version, which specifies the JSON schema for the tileset and the base set of tile formats. The `tilesetVersion` property is an optional string that defines an application-specific version of a tileset, e.g., for when an existing tileset is updated.

`properties` is an object containing objects for each per-feature property in the tileset. This tileset JSON snippet is for 3D buildings, so each tile has building models, and each building model has a `Height` property (see *Batch Table*). The name of each object in `properties` matches the name of a per-feature property, and its value defines its `minimum` and `maximum` numeric values, which are useful, for example, for creating color ramps for styling.

`geometricError` is a nonnegative number that defines the error, in meters, when the tileset is not rendered. See *Geometric error* for how geometric error is used to drive refinement.

`root` is an object that defines the root tile using the JSON described in the above section. `root.geometricError` is not the same as the tileset's top-level `geometricError`. The tileset's `geometricError` is the error when the entire tileset is not rendered; `root.geometricError` is the error when only the root tile is rendered.

`root.children` is an array of objects that define child tiles. Each child tile's content is fully enclosed by its parent tile's `boundingVolume` and, generally, a `geometricError` less than its parent tile's `geometricError`. For leaf tiles, the length of this array is zero, and `children` may not be defined.

1.7.1 External tilesets

To create a tree of trees, a tile's `content.uri` can point to an external tileset (the uri of another tileset JSON file). This enables, for example, storing each city in a tileset and then having a global tileset of tilesets.

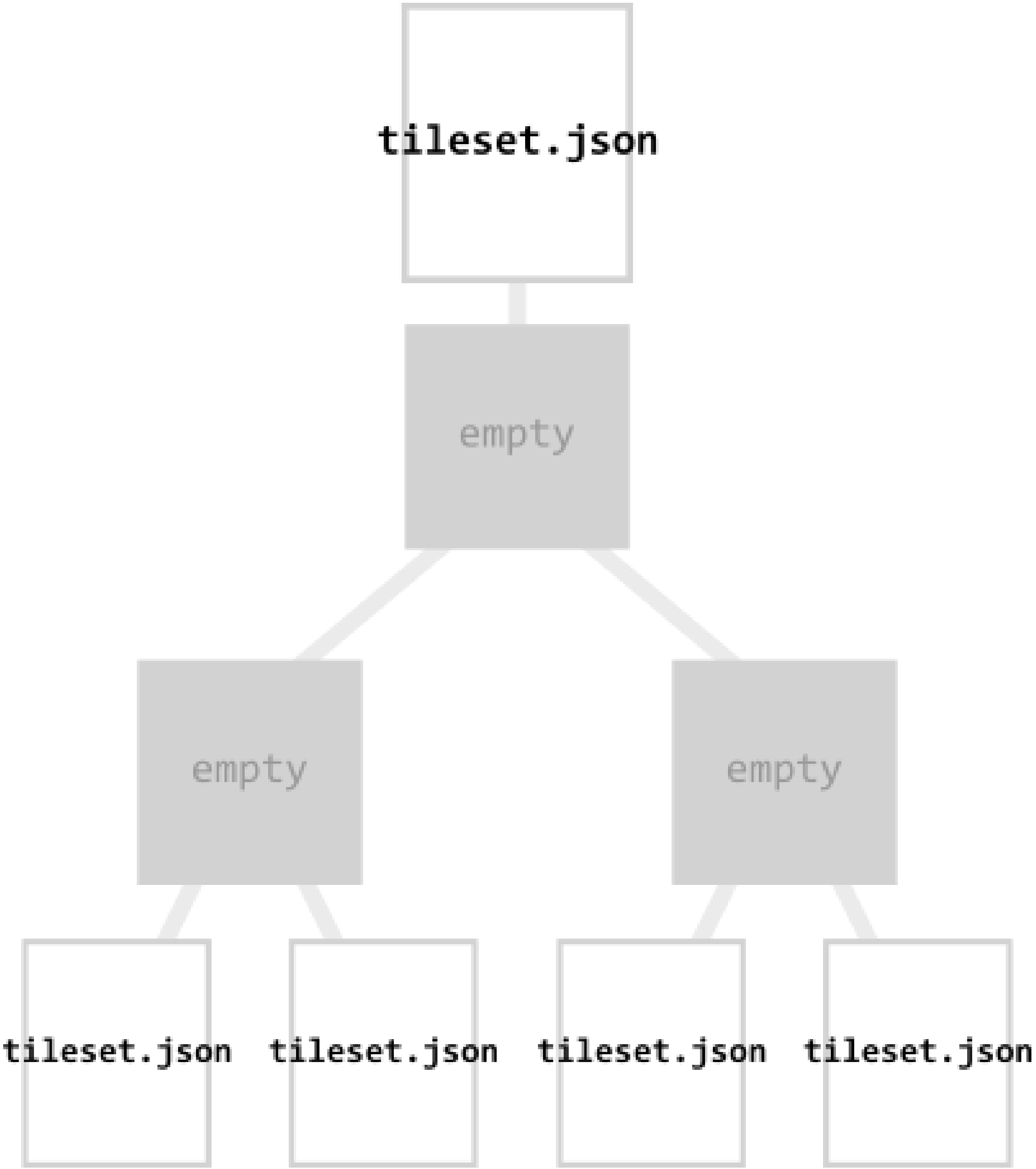


Figure 15: A tileset JSON file with external tileset JSON files.

When a tile points to an external tileset, the tile:

1. Cannot have any children; `tile.children` must be `undefined` or an empty array.
2. Cannot be used to create cycles, for example, by pointing to the same tileset file containing the tile or by pointing to another tileset file that then points back to the initial file containing the tile.
3. Will be transformed by both the tile's `transform` and root tile's `transform`. For example, in the following tileset referencing an external tileset, the computed transform for `T3` is `[T0][T1][T2][T3]`.

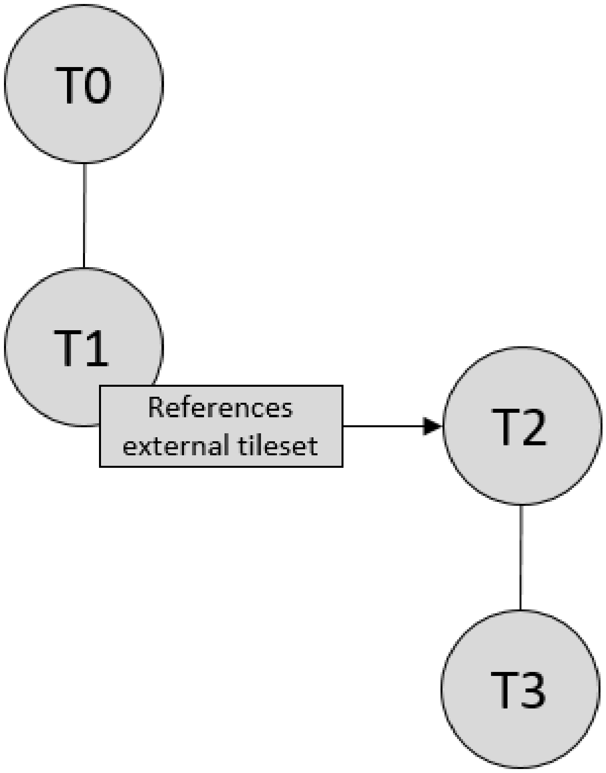


Figure 16: A tileset with transforms an external tileset with transforms

1.7.2 Geometric error

Geometric error is a nonnegative number that defines the error, in meters, introduced if this tile is rendered and its children are not. At runtime, the geometric error is used to compute *Screen-Space Error* (SSE), i.e., the error measured in pixels. The SSE determines *Hierarchical Level of Detail* (HLOD) refinement, i.e., if a tile is sufficiently detailed for the current view or if its children should be considered.

The geometric error is determined when creating the tileset and based on a metric like point density, tile sizes in meters, or another factor specific to that tileset. In general, a higher geometric error means a tile will be refined more aggressively, and children tiles will be loaded and rendered sooner.

Implementation Note: Typically, a property of the root tile, such as size, is used to determine a geometric error. Then each successive level of children uses a lower geometric error, with leaf tiles generally having a geometric error of 0.

1.7.3 Bounding volume spatial coherence

As described above, the tree has spatial coherence; each tile has a bounding volume completely enclosing its content, and the content for child tiles are completely inside the parent's bounding volume. This does not imply that a child's bounding volume is completely inside its parent's bounding volume. For example:

Bounding sphere for a terrain tile.

Bounding spheres for the four child tiles. The children's content is completely inside the parent's bounding volume, but the children's bounding volumes are not since they are not tightly fit.

1.7.4 Spatial data structures

The tree defined in a tileset by `root` and, recursively, its `children`, can define different types of spatial data structures. In addition, any combination of tile formats and refinement approach (replacement or additive) can be used, enabling a lot of flexibility to support heterogeneous datasets, see *Refinement*.

It is up to the conversion tool that generates the tileset to define an optimal tree for the dataset. A runtime engine, such as Cesium, is generic and will render any tree defined by the tileset. Here's a brief description of how 3D Tiles can represent various spatial data structures.

1.7.4.1 K-d trees

A k-d tree is created when each tile has two children separated by a *splitting plane* parallel to the *x*, *y*, or *z* axis (or latitude, longitude, height). The split axis is often round-robin rotated as levels increase down the tree, and the splitting plane may be selected using the median split, surface area heuristics, or other approaches.

Example k-d tree. Note the non-uniform subdivision.

Note that a k-d tree does not have uniform subdivision like typical 2D geospatial tiling schemes and, therefore, can create a more balanced tree for sparse and non-uniformly distributed datasets.

3D Tiles enables variations on k-d trees such as multi-way k-d trees where, at each leaf of the tree, there are multiple splits along an axis. Instead of having two children per tile, there are `n` children.

1.7.4.2 Quadtrees

A quadtree is created when each tile has four uniformly subdivided children (e.g., using the center latitude and longitude), similar to typical 2D geospatial tiling schemes. Empty child tiles can be omitted.

Classic quadtree subdivision.

3D Tiles enable quadtree variations such as non-uniform subdivision and tight bounding volumes (as opposed to bounding, for example, the full 25% of the parent tile, which is wasteful for sparse datasets).

Quadtree with tight bounding volumes around each child.

For example, here is the root tile and its children for Canary Wharf. Note the bottom left, where the bounding volume does not include the water on the left where no buildings will appear:

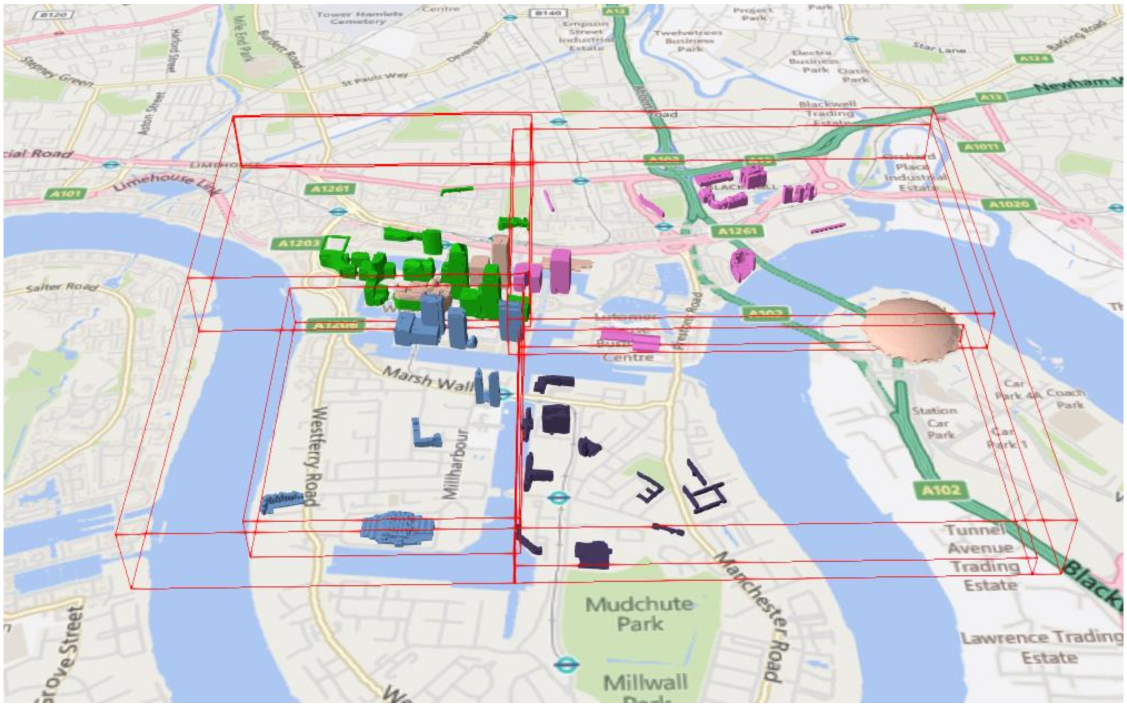


Figure 17: A root tile and its four children tiles

3D Tiles also enable other quadtree variations such as loose quadtrees, where child tiles overlap but spatial coherence is still preserved, i.e., a parent tile completely encloses all of its children. This approach can be useful to avoid splitting features, such as 3D models, across tiles.

Quadtree with non-uniform and overlapping tiles.

Below, the green buildings are in the left child and the purple buildings are in the right child. Note that the tiles overlap so the two green and one purple building in the center are not split.

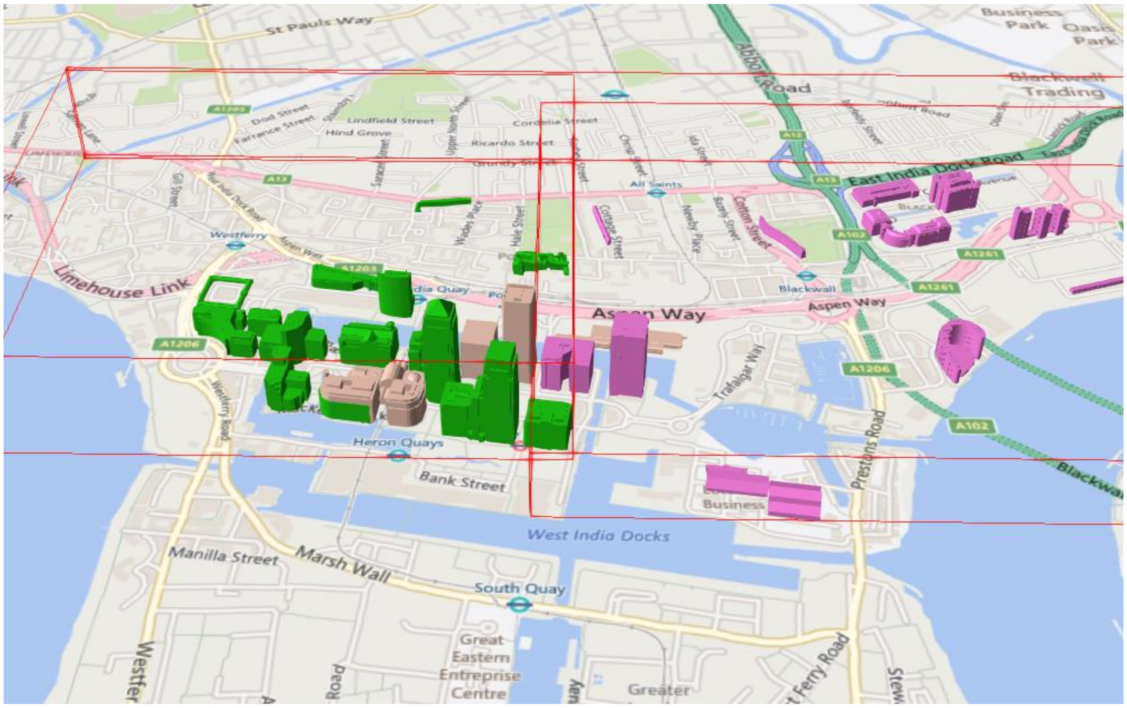


Figure 18: Two sibling tiles with overlapping bounding volumes

1.7.4.3 Octrees

An octree extends a quadtree by using three orthogonal splitting planes to subdivide a tile into eight children. Like quadtrees, 3D Tiles allows variations to octrees such as non-uniform subdivision, tight bounding volumes, and overlapping children.

Traditional octree subdivision.

Non-uniform octree subdivision for a point cloud using additive refinement. Point Cloud of the Church of St Marie at Chappes, France by Prof. Peter Allen, Columbia University Robotics Lab. Scanning by Alejandro Troccoli and Matei Ciocarlie.

1.7.4.4 Grids

3D Tiles enables uniform, non-uniform, and overlapping grids by supporting an arbitrary number of child tiles. For example, here is a top-down view of a non-uniform overlapping grid of Cambridge:

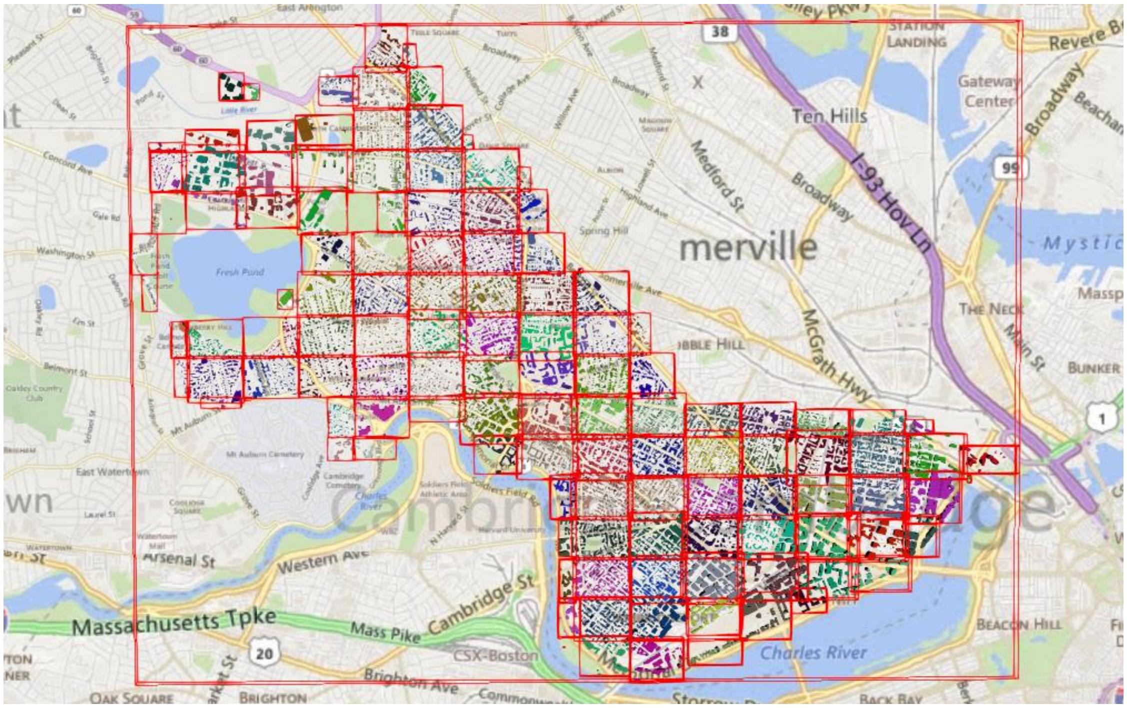


Figure 19: A tileset with an overlapping grid spatial data structure

3D Tiles takes advantage of empty tiles: those tiles that have a bounding volume, but no content. Since a tile's `content` property does not need to be defined, empty non-leaf tiles can be used to accelerate non-uniform grids with hierarchical culling. This essentially creates a quadtree or octree without hierarchical levels of detail (HLOD).

1.8 Specifying extensions and application specific extras

3D Tiles defines extensions to allow the base specification to have extensibility for new features, as well as extras to allow for application specific metadata.

1.8.1 Extensions

Extensions allow the base specification to be extended with new features. The optional `extensions` dictionary property may be added to any 3D Tiles JSON object, which contains the name of the extensions and the extension specific objects. The following example shows a tile object with a hypothetical vendor extension which specifies a separate collision volume.

```
{
  "transform": [
     4.843178171884396,   1.2424271388626869, 0,                  0,
    -0.7993325488216595,  3.1159251367235608, 3.8278032889280675, 0,
     0.9511533376784163, -3.7077466670407433, 3.2168186118075526, 0,
     1215001.7612985559, -4736269.697480114,  4081650.708604793,  1
  ],
  "boundingVolume": {
    "box": [
      0,     0,    6.701,
      3.738, 0,    0,
      0,     3.72, 0,
      0,     0,    13.402
    ]
  },
  "geometricError": 32,
  "content": {
    "uri": "building.b3dm"
  },
  "extensions": {
    "VENDOR_collision_volume": {
      "box": [
        0,     0,    6.8,
        3.8,   0,    0,
        0,     3.8,  0,
        0,     0,    13.5
      ]
    }
  }
}
```

All extensions used in a tileset or any descendant external tilesets must be listed in the entry tileset JSON in the top-level `extensionsUsed` array property, e.g.,

```
{
    "extensionsUsed": [
        "VENDOR_collision_volume"
    ]
}
```

All extensions required to load and render a tileset or any descendant external tilesets must also be listed in the entry tileset JSON in the top-level `extensionsRequired` array property, such that `extensionsRequired` is a subset of `extensionsUsed`. All values in `extensionsRequired` must also exist in `extensionsUsed`.

1.8.2 Extras

The `extras` property allows application specific metadata to be added to any 3D Tiles JSON object. The following example shows a tile object with an additional application specific name property.

```
{
  "transform": [
     4.843178171884396,   1.2424271388626869, 0,                   0,
    -0.7993325488216595,  3.1159251367235608, 3.8278032889280675, 0,
     0.9511533376784163, -3.7077466670407433, 3.2168186118075526, 0,
     1215001.7612985559, -4736269.697480114,  4081650.708604793,  1
  ],
  "boundingVolume": {
    "box": [
      0,      0,     6.701,
      3.738, 0,     0,
      0,      3.72, 0,
      0,      0,     13.402
    ]
  },
  "geometricError": 32,
  "content": {
    "uri": "building.b3dm"
  },
  "extras": {
    "name": "Empire State Building"
  }
}
```

2 Property reference

2.1.1 Tileset

A 3D Tiles tileset.

Properties

	Type	Description	Required
asset	`object`	Metadata about the entire tileset.	✓ Yes
properties	`object`	A dictionary object of metadata about per-feature properties.	No
geometricError	`number`	The error, in meters, introduced if this tileset is not rendered. At runtime, the geometric error is used to compute screen space error (SSE), i.e., the error measured in pixels.	✓ Yes
root	`object`	The root tile.	✓ Yes
extensionsUsed	`string [1-*]`	Names of 3D Tiles extensions used somewhere in this tileset.	No
extensionsRequired	`string [1-*]`	Names of 3D Tiles extensions required to properly load this tileset.	No
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are not allowed.

- **JSON schema**: tileset.schema.json

2.1.1.1 tileset.asset ✓

Metadata about the entire tileset.

- **Type**: `object`
- **Required**: Yes

2.1.1.2 tileset.properties

A dictionary object of metadata about per-feature properties.

- **Type**: `object`
- **Required**: No

2.1.1.3 tileset.geometricError ✓

The error, in meters, introduced if this tileset is not rendered. At runtime, the geometric error is used to compute screen space error (SSE), i.e., the error measured in pixels.

- **Type**: `number`
- **Required**: Yes
- **Minimum**: `>= 0`

2.1.1.4 tileset.root ✓

- **Type**: `object`
- **Required**: Yes

2.1.1.5 tileset.extensionsUsed

Names of 3D Tiles extensions used somewhere in this tileset.

- **Type**: `string [1-*]`
- Each element in the array must be unique.
- **Required**: No

2.1.1.6 tileset.extensionsRequired

Names of 3D Tiles extensions required to properly load this tileset.

- **Type**: `string [1-*]`
- Each element in the array must be unique.
- **Required**: No

2.1.1.7 tileset.extensions

- **Type**: `object`
- **Required**: No

2.1.1.8 tileset.extras

- **Type**: `any`
- **Required**: No

2.1.2 Asset

Metadata about the entire tileset.

Properties

	Type	Description	Required
version	`string`	The 3D Tiles version. The version defines the JSON schema for tileset.json and the base set of tile formats.	✓ Yes
tilesetVersion	`string`	Application-specific version of this tileset, e.g., for when an existing tileset is updated.	No
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are not allowed.

- **JSON schema**: asset.schema.json

2.1.2.1 asset.version ✓

The 3D Tiles version. The version defines the JSON schema for tileset.json and the base set of tile formats.

- **Type**: `string`
- **Required**: Yes

2.1.2.2 asset.tilesetVersion

Application-specific version of this tileset, e.g., for when an existing tileset is updated.

- **Type**: `string`
- **Required**: No

2.1.2.3 asset.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

2.1.2.4 asset.extras

Application-specific data.

- **Type**: `any`
- **Required**: No

2.1.3 Properties

A dictionary object of metadata about per-feature properties.

Properties

	Type	Description	Required
maximum	`number`	The maximum value of this property of all the features in the tileset.	✓ Yes
minimum	`number`	The minimum value of this property of all the features in the tileset.	✓ Yes
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are not allowed.

- **JSON schema**: properties.schema.json

2.1.3.1 properties.maximum ✓

The maximum value of this property of all the features in the tileset.

- **Type**: `number`
- **Required**: Yes

2.1.3.2 properties.minimum ✓

The minimum value of this property of all the features in the tileset.

- **Type**: `number`
- **Required**: Yes

2.1.3.3 properties.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

2.1.3.4 properties.extras

Application-specific data.

- **Type**: `any`

- **Required**: No

2.1.4 Tile

A tile in a 3D Tiles tileset.

Properties

	Type	Description	Required
boundingVolume	`object`	The bounding volume that encloses the tile.	✓ Yes
viewerRequestVolume	`object`	Optional bounding volume that defines the volume the viewer must be inside of before the tile's content will be requested and before the tile will be refined based on geometricError.	No
geometricError	`number`	The error, in meters, introduced if this tile is rendered and its children are not. At runtime, the geometric error is used to compute screen space error (SSE), i.e., the error measured in pixels.	✓ Yes
refine	`string`	Specifies if additive or replacement refinement is used when traversing the tileset for rendering. This property is required for the root tile of a tileset; it is optional for all other tiles. The default is to inherit from the parent tile.	No
transform	`number [16]`	A floating-point 4x4 affine transformation matrix, stored in column-major order, that transforms the tile's content--i.e., its features as well as content.boundingVolume, boundingVolume, and viewerRequestVolume--from the tile's local coordinate system to the parent tile's coordinate system, or, in the case of a root tile, from the tile's local coordinate system to the tileset's coordinate system. transform does not apply to geometricError, nor does it apply any volume property when the volume is a region, defined in EPSG:4326 coordinates.	No, default: `[1,0,0,0,0,1,0,0,0,0,1,0,0,0,0,1]`
content	`object`	Metadata about the tile's content and a	No

		link to the content. When this is omitted the tile is just used for culling. This is required for leaf tiles.	
children	`array[]`	An array of objects that define child tiles. Each child tile content is fully enclosed by its parent tile's bounding volume and, generally, has a geometricError less than its parent tile's geometricError. For leaf tiles, the length of this array is zero, and children may not be defined.	No
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are not allowed.

- **JSON schema**: tile.schema.json

2.1.4.1 tile.boundingVolume ✓

The bounding volume that encloses the tile.

- **Type**: `object`
- **Required**: Yes

2.1.4.2 tile.viewerRequestVolume

Optional bounding volume that defines the volume the viewer must be inside of before the tile's content will be requested and before the tile will be refined based on geometricError.

- **Type**: `object`
- **Required**: No

2.1.4.3 tile.geometricError ✓

The error, in meters, introduced if this tile is rendered and its children are not. At runtime, the geometric error is used to compute screen space error (SSE), i.e., the error measured in pixels.

- **Type**: `number`
- **Required**: Yes
- **Minimum**: `>= 0`

2.1.4.4 tile.refine

Specifies if additive or replacement refinement is used when traversing the tileset for rendering. This property is required for the root tile of a tileset; it is optional for all other tiles. The default is to inherit from the parent tile.

- **Type**: `string`
- **Required**: No
- **Allowed values**:
- `"ADD"`
- `"REPLACE"`

2.1.4.5 tile.transform

A floating-point 4x4 affine transformation matrix, stored in column-major order, that transforms the tile's content--i.e., its features as well as content.boundingVolume, boundingVolume, and viewerRequestVolume--from the tile's local coordinate system to the parent tile's coordinate system, or, in the case of a root tile, from the tile's local coordinate system to the tileset's coordinate system. transform does not apply to geometricError, nor does it apply any volume property when the volume is a region, defined in EPSG:4326 coordinates.

- **Type**: `number [16]`
- **Required**: No, default: `[1,0,0,0,0,1,0,0,0,0,1,0,0,0,0,1]`

2.1.4.6 tile.content

Metadata about the tile's content and a link to the content. When this is omitted the tile is just used for culling. This is required for leaf tiles.

- **Type**: `object`
- **Required**: No

2.1.4.7 tile.children

An array of objects that define child tiles. Each child tile content is fully enclosed by its parent tile's bounding volume and, generally, has a geometricError less than its parent tile's geometricError. For leaf tiles, the length of this array is zero, and children may not be defined.

- **Type**: `array[]`
- Each element in the array must be unique.
- **Required**: No

2.1.4.8 tile.extensions

- **Type**: `object`
- **Required**: No

2.1.4.9 tile.extras

- **Type**: `any`
- **Required**: No

2.1.5 Bounding Volume

A bounding volume that encloses a tile or its content. Exactly one property is required.

Properties

	Type	Description	Required
box	`number [12]`	An array of 12 numbers that define an oriented bounding box. The first three elements define the x, y, and z values for the center of the box. The next three elements (with indices 3, 4, and 5) define the x axis direction and half-length. The next three elements (indices 6, 7, and 8) define the y axis direction and half-length. The last three elements (indices 9, 10, and 11) define the z axis direction and half-length.	No
region	`number [6]`	An array of six numbers that define a bounding geographic region in EPSG:4326 coordinates with the order [west, south, east, north, minimum height, maximum height]. Longitudes and latitudes are in radians, and heights are in meters above (or below) the WGS84 ellipsoid.	No
sphere	`number [4]`	An array of four numbers that define a bounding sphere. The first three elements define the x, y, and z values for the center of the sphere. The last element (with index 3) defines the radius in meters.	No
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are not allowed.

- **JSON schema**: boundingVolume.schema.json

2.1.5.1 boundingVolume.box

An array of 12 numbers that define an oriented bounding box. The first three elements define the x, y, and z values for the center of the box. The next three elements (with indices 3, 4, and 5) define the x axis direction and half-length. The next three elements (indices 6, 7, and 8) define the y axis direction and half-length. The last three elements (indices 9, 10, and 11) define the z axis direction and half-length.

- **Type**: `number [12]`
- **Required**: No

2.1.5.2 boundingVolume.region

An array of six numbers that define a bounding geographic region in EPSG:4326 coordinates with the order [west, south, east, north, minimum height, maximum height].

Longitudes and latitudes are in radians, and heights are in meters above (or below) the WGS84 ellipsoid.

- **Type**: `number [6]`
- **Required**: No

2.1.5.3 boundingVolume.sphere

An array of four numbers that define a bounding sphere. The first three elements define the x, y, and z values for the center of the sphere. The last element (with index 3) defines the radius in meters.

- **Type**: `number [4]`
- **Required**: No

2.1.5.4 boundingVolume.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

2.1.5.5 boundingVolume.extras

Application-specific data.

- **Type**: `any`
- **Required**: No

2.1.6 Tile Content

Metadata about the tile's content and a link to the content.

Properties

	Type	Description	Required
boundingVolume	`object`	A bounding volume that encloses a tile or its content. Exactly one property is required.	No
uri	`string`	A uri that points to the tile's content. When the uri is relative, it is relative to the referring tileset.json.	✓ Yes
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are not allowed.

- **JSON schema**: tile.content.schema.json

2.1.6.1 tile.content.boundingVolume

A bounding volume that encloses a tile or its content. Exactly one property is required.

- **Type**: `object`
- **Required**: No

2.1.6.2 tile.content.uri ✓

A uri that points to the tile's content. When the uri is relative, it is relative to the referring tileset.json.

- **Type**: `string`
- **Required**: Yes

2.1.6.3 tile.content.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

2.1.6.4 tile.content.extras

Application-specific data.

- **Type**: `any`
- **Required**: No

2.1.7 Extension

Dictionary object with extension-specific objects.

Additional properties are allowed.

- **JSON schema**: extension.schema.json

2.1.8 Extras

Application-specific data.

3 Feature Table

3.1 Overview

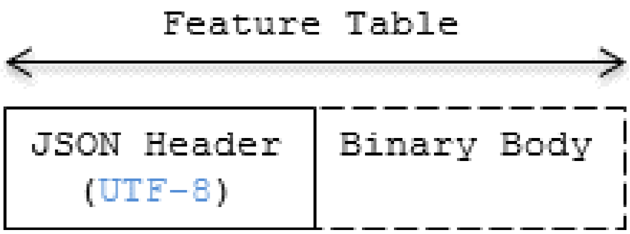
A *Feature Table* describes position and appearance properties for each feature in a tile. The Batch Table, on the other hand, contains per-feature application-specific metadata not necessarily used for rendering.

A Feature Table is used by tile formats like Batched 3D Model (b3dm) where each model is a feature, and Point Cloud (pnts) where each point is a feature.

Per-feature properties are defined using tile format-specific semantics defined in each tile format's specification. For example, for *Instanced 3D Model*, `SCALE_NON_UNIFORM` defines the non-uniform scale applied to each 3D model instance.

3.2 Layout

A Feature Table is composed of two parts: a JSON header and an optional binary body in little endian. The JSON property names are tile format-specific semantics, and their values can either be defined directly in the JSON, or refer to sections in the binary body. It is more efficient to store long numeric arrays in the binary body. The following figure shows the Feature Table layout:



feature table layout

When a tile format includes a Feature Table, the Feature Table immediately follows the tile's header. The header will also contain `featureTableJSONByteLength` and `featureTableBinaryByteLength` `uint32` fields, which can be used to extract each respective part of the Feature Table.

3.2.1 Padding

The Feature Table binary body must start and end on an 8-byte alignment within the containing tile binary.

The JSON header must be padded with trailing Space characters (`0x20`) to satisfy alignment requirements of the Feature Table binary (if present).

3.2.2 JSON header

Feature Table values can be represented in the JSON header in three different ways:

1. A single value or object, e.g., `"INSTANCES_LENGTH" : 4`.

- This is used for global semantics like `"INSTANCES_LENGTH"`, which defines the number of model instances in an Instanced 3D Model tile.

2. An array of values, e.g., `"POSITION" : [1.0, 0.0, 0.0, 0.0, 1.0, 0.0, 0.0, 0.0, 1.0]`.

- This is used for per-feature semantics like `"POSITION"` in Instanced 3D Model. Above, each `POSITION` refers to a `float32[3]` data type so there are three features: `Feature 0's position=(1.0, 0.0, 0.0)`, `Feature 1's position=(0.0, 1.0, 0.0)`, `Feature 2's position=(0.0, 0.0, 1.0)`.

3. A reference to data in the binary body, denoted by an object with a `byteOffset` property, e.g., `"SCALE" : { "byteOffset" : 24}`.

- `byteOffset` specifies a zero-based offset relative to the start of the binary body. The value of `byteOffset` must be a multiple of the size of the property's `componentType`, e.g., the `"POSITION"` property, which has the component `FLOAT`, must start at an offset of a multiple of `4`.
- The semantic defines the allowed data type, e.g., when `"POSITION"` in Instanced 3D Model refers to the binary body, the component type is `FLOAT` and the number of components is `3`.
- Some semantics allow for overriding the implicit `componentType`. These cases are specified in each tile format, e.g., `"BATCH_ID" : { "byteOffset" : 24, "componentType" : "UNSIGNED_BYTE"}`. The only valid properties in the JSON header are the defined semantics by the tile format and optional `extras` and `extensions` properties. Application-specific data should be stored in the Batch Table.

3.2.2.1 Property Reference

3.2.2.1.1 Extension

Dictionary object with extension-specific objects.

Additional properties are allowed.

- **JSON schema**: extension.schema.json

3.2.2.1.2 Extras

Application-specific data.

3.2.2.1.3 Feature Table

A set of semantics containing per-tile and per-feature values defining the position and appearance properties for features in a tile.

Properties

	Type	Description	Required
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are not allowed.

- **JSON schema**: featureTable.schema.json

3.2.2.1.3.1 feature.table.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

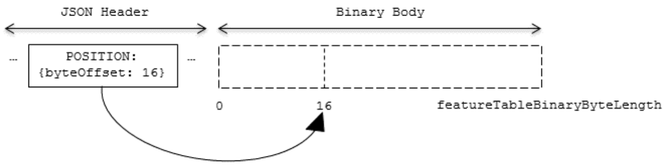
3.2.2.1.3.2 feature.table.extras

Application-specific data.

- **Type**: `any`
- **Required**: No

3.2.3 Binary body

When the JSON header includes a reference to the binary, the provided `byteOffset` is used to index into the data. The following figure shows indexing into the Feature Table binary body:



feature table binary index

Values can be retrieved using the number of features, `featuresLength`; the desired feature id, `featureId`; and the data type (component type and number of components) for the feature semantic.

4 Batch Table

4.1 Overview

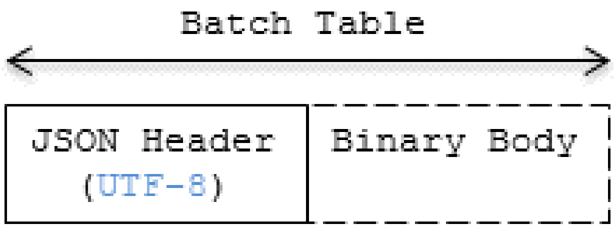
A *Batch Table* contains per-feature application-specific metadata in a tile. These properties may be queried at runtime for declarative styling and application-specific use cases such as populating a UI or issuing a REST API request. Some example Batch Table properties are building heights, geographic coordinates, and database primary keys.

A Batch Table is used by the following tile formats:

- Batched 3D Model (b3dm)
- Instanced 3D Model (i3dm)
- Point Cloud (pnts)

4.2 Layout

A Batch Table is composed of two parts: a JSON header and an optional binary body in little endian. The JSON describes the properties, whose values either can be defined directly in the JSON as an array, or can refer to sections in the binary body. It is more efficient to store long numeric arrays in the binary body. The following figure shows the Batch Table layout:



batch table layout

When a tile format includes a Batch Table, the Batch Table immediately follows the tile's Feature Table. The header will also contain `batchTableJSONByteLength` and `batchTableBinaryByteLength` `uint32` fields, which can be used to extract each respective part of the Batch Table.

4.2.1 Padding

The Batch Table binary body must start and end on an 8-byte alignment within the containing tile binary.

The JSON header must be padded with trailing Space characters (`0x20`) to satisfy alignment requirements of the Batch Table binary (if present).

4.2.2 JSON header

Batch Table values can be represented in the JSON header in two different ways:

1. An array of values, e.g., `"name" : ['name1', 'name2', 'name3']` or `"height" : [10.0, 20.0, 15.0]`.
   - Array elements can be any valid JSON data type, including objects and arrays. Elements may be `null`.
   - The length of each array is equal to `batchLength`, which is specified in each tile format. This is the number of features in the tile. For example, `batchLength` may be the number of models in a b3dm tile, the number of instances in a i3dm tile, or the number of points (or number of objects) in a pnts tile.
2. A reference to data in the binary body, denoted by an object with `byteOffset`, `componentType`, and `type` properties, e.g., `"height" : { "byteOffset" : 24, "componentType" : "FLOAT", "type" : "SCALAR"}`.
   - `byteOffset` specifies a zero-based offset relative to the start of the binary body. The value of `byteOffset` must be a multiple of the size of the property's `componentType`, e.g., a property with the component type of `FLOAT` must start at an offset of a multiple of `4`.
   - `componentType` is the datatype of components in the attribute. Allowed values are `"BYTE"`, `"UNSIGNED_BYTE"`, `"SHORT"`, `"UNSIGNED_SHORT"`, `"INT"`, `"UNSIGNED_INT"`, `"FLOAT"`, and `"DOUBLE"`.
   - `type` specifies if the property is a scalar or vector. Allowed values are `"SCALAR"`, `"VEC2"`, `"VEC3"`, and `"VEC4"`.

The Batch Table JSON is a `UTF-8` string containing JSON.

Implementation Note: In JavaScript, the Batch Table JSON can be extracted from an `ArrayBuffer` using the `TextDecoder` JavaScript API and transformed to a JavaScript object with `JSON.parse`.

A `batchId` is used to access elements in each array and extract the corresponding properties. For example, the following Batch Table has properties for a batch of two features:

```
{
    "id" : ["unique id", "another unique id"],
    "displayName" : ["Building name", "Another building name"],
    "yearBuilt" : [1999, 2015],
    "address" : [{"street" : "Main Street", "houseNumber" : "1"}, {"street" :
"Main Street", "houseNumber" : "2"}]
}
```

The properties for the feature with `batchId = 0` are

```
id[0] = 'unique id';
displayName[0] = 'Building name';
yearBuilt[0] = 1999;
address[0] = {street : 'Main Street', houseNumber : '1'};
```

The properties for `batchId = 1` are

```
id[1] = 'another unique id';
displayName[1] = 'Another building name';
yearBuilt[1] = 2015;
address[1] = {street : 'Main Street', houseNumber : '2'};
```

4.2.2.1 Property reference

- Batch Table
- Extension
- Extras
- property
- binaryBodyReference

4.2.2.1.1 Batch Table

A set of properties defining application-specific metadata for features in a tile.

Properties

	Type	Description	Required
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are allowed.

- **JSON schema**: batchTable.schema.json

4.2.2.1.1.1 batch.table.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

4.2.2.1.1.2 batch.table.extras

Application-specific data.

- **Type**: `any`
- **Required**: No

4.2.2.2 Additional properties

4.2.2.2.1 binaryBodyReference

Properties

	Type	Description	Required
byteOffset	`integer`		✓ Yes
componentType	`string`		✓ Yes
type	`string`		✓ Yes

Additional properties are allowed.

- **JSON schema**: #/definitions/binaryBodyReference

4.2.2.2.1.1 binarybodyreference.byteOffset ✓

- **Type**: `integer`
- **Required**: Yes
- **Minimum**: `>= 0`

4.2.2.2.1.2 binarybodyreference.componentType ✓

- **Type**: `string`
- **Required**: Yes
- **Allowed values**:
- `"BYTE"`
- `"UNSIGNED_BYTE"`
- `"SHORT"`
- `"UNSIGNED_SHORT"`
- `"INT"`
- `"UNSIGNED_INT"`
- `"FLOAT"`
- `"DOUBLE"`

4.2.2.2.1.3 binarybodyreference.type ✓

- **Type**: `string`
- **Required**: Yes
- **Allowed values**:
- `"SCALAR"`
- `"VEC2"`
- `"VEC3"`
- `"VEC4"`

4.2.2.2.2 Extension

Dictionary object with extension-specific objects.

Additional properties are allowed.

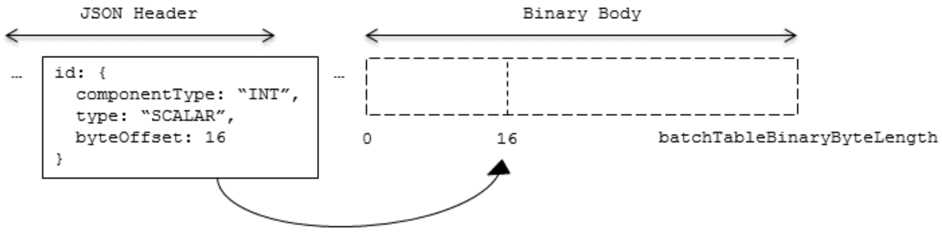
- **JSON schema**: extension.schema.json

4.2.2.2.3 Extras

Application-specific data.

4.2.3 Binary body

When the JSON header includes a reference to the binary section, the provided `byteOffset` is used to index into the data, as shown in the following figure:



batch table binary index

Values can be retrieved using the number of features, `batchLength`; the desired batch id, `batchId`; and the `componentType` and `type` defined in the JSON header.

The following tables can be used to compute the byte size of a property.

`componentType`	Size in bytes
`"BYTE"`	1
`"UNSIGNED_BYTE"`	1
`"SHORT"`	2
`"UNSIGNED_SHORT"`	2
`"INT"`	4
`"UNSIGNED_INT"`	4
`"FLOAT"`	4
`"DOUBLE"`	8

`type`	Number of components
`"SCALAR"`	1
`"VEC2"`	2
`"VEC3"`	3
`"VEC4"`	4

5 Tile format specifications

Each tile's `content.uri` property points to a tile that is one of the formats listed in the table below.

Format	Uses
Batched 3D Model (b3dm)	Heterogeneous 3D models. E.g. textured terrain and surfaces, 3D building exteriors and interiors, massive models.
Instanced 3D Model (i3dm)	3D model instances. E.g. trees, windmills, bolts.
Point Cloud (pnts)	Massive number of points.
Composite (cmpt)	Concatenate tiles of different formats into one tile.

A tileset can contain any combination of tile formats. 3D Tiles may also support different formats in the same tile using a Composite tile.

5.1 Batched 3D Model

5.1.1 Overview

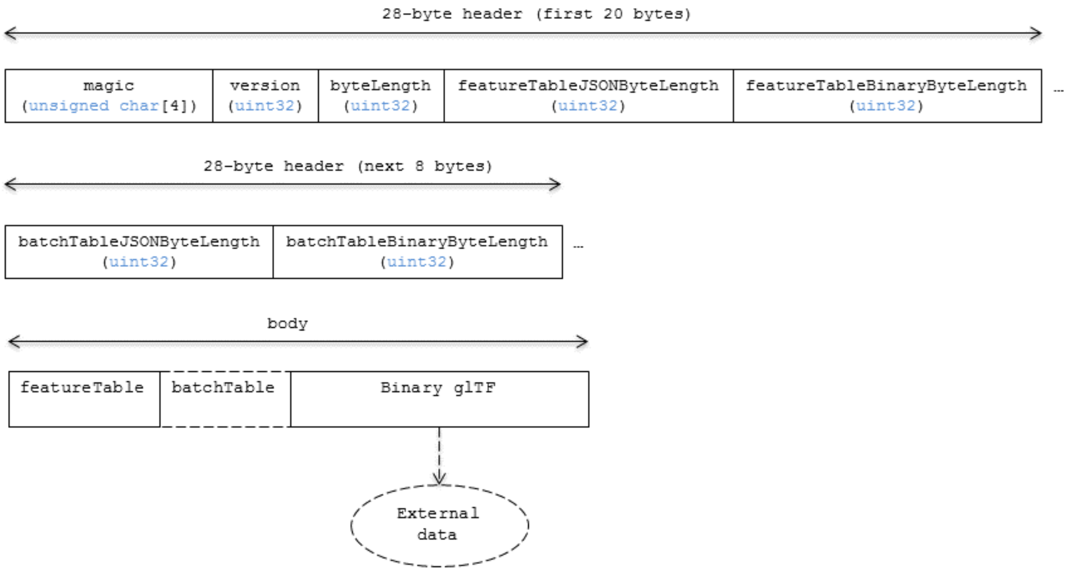
Batched 3D Model allows offline batching of heterogeneous 3D models, such as different buildings in a city, for efficient streaming to a web client for rendering and interaction. Efficiency comes from transferring multiple models in a single request and rendering them in the least number of WebGL draw calls necessary. Using the core 3D Tiles spec language, each model is a *feature*.

Per-model properties, such as IDs, enable individual models to be identified and updated at runtime, e.g., show/hide, highlight color, etc. Properties may be used, for example, to query a web service to access metadata, such as passing a building's ID to get its address. Or a property might be referenced on the fly for changing a model's appearance, e.g., changing highlight color based on a property value.

A Batched 3D Model tile is a binary blob in little endian.

5.1.2 Layout

A tile is composed of two sections: a header immediately followed by a body. The following figure shows the Batched 3D Model layout (dashes indicate optional fields):


28-byte header (first 20 bytes)
magic (unsigned char[4])
version (uint32)
byteLength (uint32)
featureTableJSONByteLength (uint32)
featureTableBinaryByteLength (uint32)
...
28-byte header (next 8 bytes)
batchTableJSONByteLength (uint32)
batchTableBinaryByteLength (uint32)
...
body
featureTable
batchTable
Binary glTF
External data

5.1.2.1 Padding

A tile's `byteLength` must be aligned to an 8-byte boundary. The contained Feature Table and Batch Table must conform to their respective padding requirement.

The binary glTF must start and end on an 8-byte alignment so that glTF's byte-alignment guarantees are met. This can be done by padding the Feature Table or Batch Table if they are present.

5.1.3 Header

The 28-byte header contains the following fields:

Field name	Data type	Description
`magic`	4-byte ANSI string	`"b3dm"`. This can be used to identify the content as a Batched 3D Model tile.
`version`	`uint32`	The version of the Batched 3D Model format. It is currently `1`.
`byteLength`	`uint32`	The length of the entire tile, including the header, in bytes.
`featureTableJSONByteLength`	`uint32`	The length of the Feature Table JSON section in bytes.
`featureTableBinaryByteLength`	`uint32`	The length of the Feature Table binary section in

		bytes.
`batchTableJSONByteLength`	`uint32`	The length of the Batch Table JSON section in bytes. Zero indicates there is no Batch Table.
`batchTableBinaryByteLength`	`uint32`	The length of the Batch Table binary section in bytes. If `batchTableJSONByteLength` is zero, this will also be zero.

The body section immediately follows the header section, and is composed of three fields: `Feature Table`, `Batch Table`, and `Binary glTF`.

5.1.4 Feature Table

Contains values for `b3dm` semantics. More information is available in the Feature Table specification.

5.1.4.1 Property Reference

Batched 3D Model Feature Table

A set of Batched 3D Model semantics that contain additional information about features in a tile.

Properties

	Type	Description	Required
BATCH_LENGTH		✓ Yes	
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No

Additional properties are not allowed.

- **JSON schema**: featureTable.schema.json

feature.table.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

feature.table.extras

Application-specific data.

- **Type**: `any`

- **Required**: No

5.1.4.2 Semantics

Feature semantics

There are currently no per-feature semantics.

Global semantics

These semantics define global properties for all features.

Semantic	Data Type	Description	Required
`BATCH_LENGTH`	`uint32`	The number of distinguishable models, also called features, in the batch. If the Binary glTF does not have a `batchId` attribute, this field *must* be `0`.	✓ Yes.
`RTC_CENTER`	`float32[3]`	A 3-component array of numbers defining the center position when positions are defined relative-to-center, (see Coordinate system).	✗ No.

5.1.5 Batch Table

The *Batch Table* contains per-model application-specific metadata, indexable by `batchId`, that can be used for declarative styling and application-specific use cases such as populating a UI or issuing a REST API request. In the binary glTF section, each vertex has a numeric `batchId` attribute in the integer range `[0, number of models in the batch - 1]`. The `batchId` indicates the model to which the vertex belongs. This allows models to be batched together and still be identifiable.

See the Batch Table reference for more information.

5.1.6 Binary glTF

Batched 3D Model uses glTF 2.0 to embed model data.

The binary glTF immediately follows the Feature Table and Batch Table. It may embed all of its geometry, texture, and animations, or it may refer to external sources for some or all of these data.

As described above, each vertex has a `batchId` attribute indicating the model to which it belongs. For example, vertices for a batch with three models may look like this:

```
batchId:  [0,   0,   0,   ..., 1,   1,   1,   ..., 2,   2,   2,   ...]
position: [xyz, xyz, xyz, ..., xyz, xyz, xyz, ..., xyz, xyz, xyz, ...]
normal:   [xyz, xyz, xyz, ..., xyz, xyz, xyz, ..., xyz, xyz, xyz, ...]
```

Vertices do not need to be ordered by `batchId`, so the following is also OK:

```
batchId:  [0,   1,   2,   ..., 2,   1,   0,   ..., 1,   2,   0,   ...]
position: [xyz, xyz, xyz, ..., xyz, xyz, xyz, ..., xyz, xyz, xyz, ...]
normal:   [xyz, xyz, xyz, ..., xyz, xyz, xyz, ..., xyz, xyz, xyz, ...]
```

Note that a vertex can't belong to more than one model; in that case, the vertex needs to be duplicated so the `batchId`s can be assigned.

The `batchId` parameter is specified in a glTF mesh primitive by providing the `_BATCHID` attribute semantic, along with the index of the `batchId` accessor. For example,

```
"primitives": [
    {
        "attributes": {
            "_BATCHID": 0
        }
    }
]
```

```
{
    "accessors": [
        {
            "bufferView": 1,
            "byteOffset": 0,
            "componentType": 5125,
            "count": 4860,
            "max": [2],
            "min": [0],
            "type": "SCALAR"
        }
    ]
}
```

The `accessor.type` must be a value of `"SCALAR"`. All other properties must conform to the glTF schema, but have no additional requirements.

When a Batch Table is present or the `BATCH_LENGTH` property is greater than `0`, the `_BATCHID` attribute is required; otherwise, it is not.

5.1.6.1 Coordinate system

By default embedded glTFs use a right handed coordinate system where the *y*-axis is up. For consistency with the *z*-up coordinate system of 3D Tiles, glTFs must be transformed at runtime. See coordinate reference system for more details.

Vertex positions may be defined relative-to-center for high-precision rendering, see Precisions, Precisions. If defined, `RTC_CENTER` specifies the center position that all vertex positions are relative to after the coordinate system transform and glTF node hierarchy transforms have been applied.

5.1.7 File extension and MIME type

Batched 3D Model tiles use the `.b3dm` extension and `application/octet-stream` MIME type.

An explicit file extension is optional. Valid implementations may ignore it and identify a content's format by the `magic` field in its header.

5.2 Instanced 3D Model

5.2.1 Overview

Instanced 3D Model is a tile format for efficient streaming and rendering of a large number of models, called *instances*, with slight variations. In the simplest case, the same tree model, for example, may be located—or *instanced*—in several places. Each instance references the same model and has per-instance properties, such as position. Using the core 3D Tiles spec language, each instance is a *feature*.

In addition to trees, Instanced 3D Model is useful for exterior features such as fire hydrants, sewer caps, lamps, and traffic lights, and for interior CAD features such as bolts, valves, and electrical outlets.

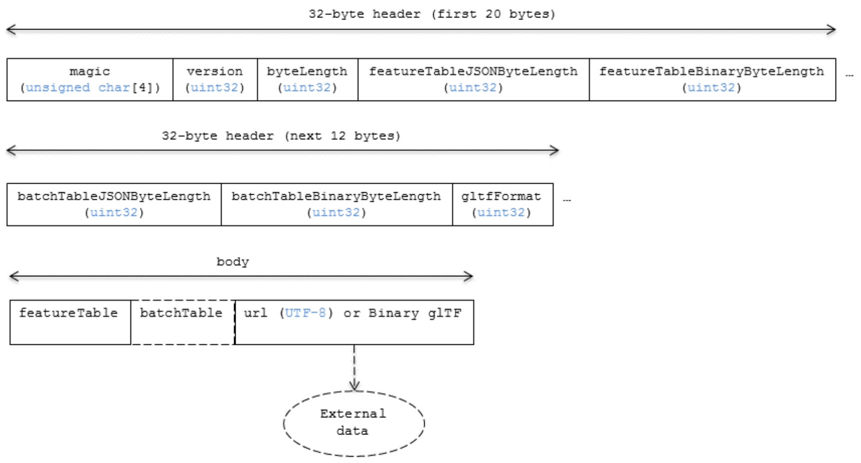
An Instanced 3D Model tile is a binary blob in little endian.

Implementation Note: A Composite tile can be used to create tiles with different types of instanced models, e.g., trees and traffic lights by combing two Instanced 3D Model tiles.

Implementation Note: Instanced 3D Model maps well to the ANGLE_instanced_arrays extension for efficient rendering with WebGL.

5.2.2 Layout

A tile is composed of a header section immediately followed by a binary body. The following figure shows the Instanced 3D Model layout (dashes indicate optional fields):


32-byte header (first 20 bytes)
magic (unsigned char[4])
version (uint32)
byteLength (uint32)
featureTableJSONByteLength (uint32)
featureTableBinaryByteLength (uint32)
...
32-byte header (next 12 bytes)
batchTableJSONByteLength (uint32)
batchTableBinaryByteLength (uint32)
gltfFormat (uint32)
...
body
featureTable
batchTable
url (UTF-8) or Binary glTF
External data

header layout

5.2.2.1 Padding

A tile's `byteLength` must be aligned to an 8-byte boundary. The contained Feature Table and Batch Table must conform to their respective padding requirement.

The binary glTF (if present) must start and end on an 8-byte alignment so that glTF's byte-alignment guarantees are met. This can be done by padding the Feature Table or Batch Table if they are present.

Otherwise, if the glTF field is a UTF-8 string, it must be padded with trailing Space characters (`0x20`) to satisfy alignment requirements of the tile, which must be removed at runtime before requesting the glTF asset.

5.2.3 Header

The 32-byte header contains the following fields:

Field name	Data type	Description
`magic`	4-byte ANSI string	`"i3dm"`. This can be used to identify the content as an Instanced 3D Model tile.
`version`	`uint32`	The version of the Instanced 3D Model format. It is currently `1`.
`byteLength`	`uint32`	The length of the entire tile, including the header, in bytes.
`featureTableJSONByteLength`	`uint32`	The length of the Feature Table JSON section in bytes.
`featureTableBinaryByteLength`	`uint32`	The length of the Feature Table binary section in bytes.
`batchTableJSONByteLength`	`uint32`	The length of the Batch Table JSON section in bytes. Zero indicates that there is no Batch

		Table.
`batchTableBinaryByteLength`	`uint32`	The length of the Batch Table binary section in bytes. If `batchTableJSONByteLength` is zero, this will also be zero.
`gltfFormat`	`uint32`	Indicates the format of the glTF field of the body. `0` indicates it is a uri, `1` indicates it is embedded binary glTF. See the glTF section below.

The body section immediately follows the header section and is composed of three fields: `Feature Table`, `Batch Table`, and `glTF`.

5.2.4 Feature Table

The Feature Table contains values for `i3dm` semantics used to create instanced models. More information is available in the Feature Table specification.

5.2.4.1 Property reference

5.2.4.1.1 Instanced 3D Model Feature Table

A set of Instanced 3D Model semantics that contains values defining the position and appearance properties for instanced models in a tile.

Properties

	Type	Description	Required
extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No
POSITION	`object`		No
POSITION_QUANTIZED	`object`		No
NORMAL_UP	`object`		No
NORMAL_RIGHT	`object`		No
NORMAL_UP_OCT32P	`object`		No
NORMAL_RIGHT_OCT32P	`object`		No
SCALE	`object`		No
SCALE_NON_UNIFORM	`object`		No
BATCH_ID	`object`		No
INSTANCES_LENGTH	`object`		✓ Yes
QUANTIZED_VOLUME_OFFSET	`object`		No
QUANTIZED_VOLUME_SCALE	`object`		No

Additional properties are not allowed.

- **JSON schema**: i3dm.featureTable.schema.json

5.2.4.1.1.1 instanced.3d.model.feature.table.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

5.2.4.1.1.2 instanced.3d.model.feature.table.extras

Application-specific data.

- **Type**: `any`
- **Required**: No

5.2.4.1.1.3 instanced.3d.model.feature.table.POSITION

- **Type**: `object`
- **Required**: No

5.2.4.1.1.4 instanced.3d.model.feature.table.POSITION_QUANTIZED

- **Type**: `object`
- **Required**: No

5.2.4.1.1.5 instanced.3d.model.feature.table.NORMAL_UP

- **Type**: `object`
- **Required**: No

5.2.4.1.1.6 instanced.3d.model.feature.table.NORMAL_RIGHT

- **Type**: `object`
- **Required**: No

5.2.4.1.1.7 instanced.3d.model.feature.table.NORMAL_UP_OCT32P

- **Type**: `object`
- **Required**: No

5.2.4.1.1.8 instanced.3d.model.feature.table.NORMAL_RIGHT_OCT32P

- **Type**: `object`
- **Required**: No

5.2.4.1.1.9 instanced.3d.model.feature.table.SCALE

- **Type**: `object`
- **Required**: No

5.2.4.1.1.10 instanced.3d.model.feature.table.SCALE_NON_UNIFORM

- **Type**: `object`

- **Required**: No

5.2.4.1.1.11 instanced.3d.model.feature.table.BATCH_ID

- **Type**: `object`
- **Required**: No

5.2.4.1.1.12 instanced.3d.model.feature.table.INSTANCES_LENGTH ✓

- **Type**: `object`
- **Required**: Yes
- **Allowed values**:

5.2.4.1.1.13 instanced.3d.model.feature.table.QUANTIZED_VOLUME_OFFSET

- **Type**: `object`
- **Required**: No
- **Allowed values**:

5.2.4.1.1.14 instanced.3d.model.feature.table.QUANTIZED_VOLUME_SCALE

- **Type**: `object`
- **Required**: No
- **Allowed values**:

5.2.4.2 Semantics

5.2.4.2.1 Instance semantics

These semantics map to an array of feature values that are used to create instances. The length of these arrays must be the same for all semantics and is equal to the number of instances. The value for each instance semantic must be a reference to the Feature Table binary body; they cannot be embedded in the Feature Table JSON header.

If a semantic has a dependency on another semantic, that semantic must be defined. If both `SCALE` and `SCALE_NON_UNIFORM` are defined for an instance, both scaling operations will be applied. If both `POSITION` and `POSITION_QUANTIZED` are defined for an instance, the higher precision `POSITION` will be used. If `NORMAL_UP`, `NORMAL_RIGHT`, `NORMAL_UP_OCT32P`, and `NORMAL_RIGHT_OCT32P` are defined for an instance, the higher precision `NORMAL_UP` and `NORMAL_RIGHT` will be used.

Semantic	Data Type	Description	Required
`POSITION`	`float32[3]`	A 3-component array of numbers containing x, y, and z Cartesian coordinates for the position of the instance.	✓ Yes, unless `POSITION_QUANTIZED` is defined.
`POSITION_QUANTIZED`	`uint16[3]`	A 3-component array of numbers containing	✓ Yes, unless `POSITION` is defined.

		x, y, and z in quantized Cartesian coordinates for the position of the instance.	
NORMAL_UP	float32[3]	A unit vector defining the up direction for the orientation of the instance.	✗ No, unless NORMAL_RIGHT is defined.
NORMAL_RIGHT	float32[3]	A unit vector defining the right direction for the orientation of the instance. Must be orthogonal to up.	✗ No, unless NORMAL_UP is defined.
NORMAL_UP_OCT32P	uint16[2]	An oct-encoded unit vector with 32-bits of precision defining the up direction for the orientation of the instance.	✗ No, unless NORMAL_RIGHT_OCT32P is defined.
NORMAL_RIGHT_OCT32P	uint16[2]	An oct-encoded unit vector with 32-bits of precision defining the right direction for the orientation of the instance. Must be orthogonal to up.	✗ No, unless NORMAL_UP_OCT32P is defined.
SCALE	float32	A number defining a scale to apply to all axes of the instance.	✗ No.
SCALE_NON_UNIFORM	float32[3]	A 3-component array of numbers defining the scale to apply to the x, y, and z axes of the instance.	✗ No.
BATCH_ID	uint8, uint16 (default), or uint32	The batchId of the instance that can be used to retrieve metadata from the Batch Table.	✗ No.

5.2.4.2.2 Global semantics

These semantics define global properties for all instances.

Semantic	Data Type	Description	Required
`INSTANCES_LENGTH`	`uint32`	The number of instances to generate. The length of each array value for an instance semantic should be equal to this.	✓ Yes.
`RTC_CENTER`	`float32[3]`	A 3-component array of numbers defining the center position when instance positions are defined relative-to-center.	✗ No.
`QUANTIZED_VOLUME_OFFSET`	`float32[3]`	A 3-component array of numbers defining the offset for the quantized volume.	✗ No, unless `POSITION_QUANTIZED` is defined.
`QUANTIZED_VOLUME_SCALE`	`float32[3]`	A 3-component array of numbers defining the scale for the quantized volume.	✗ No, unless `POSITION_QUANTIZED` is defined.
`EAST_NORTH_UP`	`boolean`	When `true` and per-instance orientation is not defined, each instance will default to	✗ No.

the `east/north/up` reference frame's orientation on the `WGS84` ellipsoid.

Examples using these semantics can be found in the examples section.

5.2.4.3 Instance orientation

An instance's orientation is defined by an orthonormal basis created by an `up` and `right` vector. The orientation will be transformed by the tile transform.

The `x` vector in the standard basis maps to the `right` vector in the transformed basis, and the `y` vector maps to the `up` vector. The `z` vector would map to a `forward` vector, but it is omitted because it will always be the cross product of `right` and `up`.

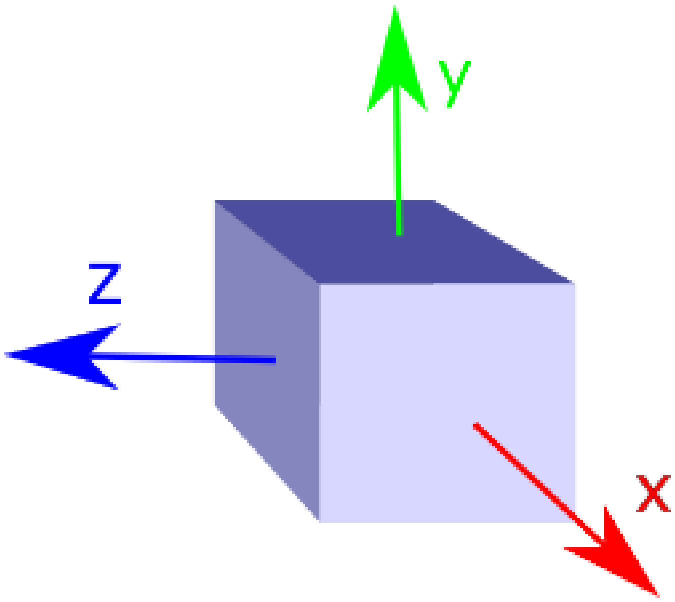


Figure 20: A box in the standard basis

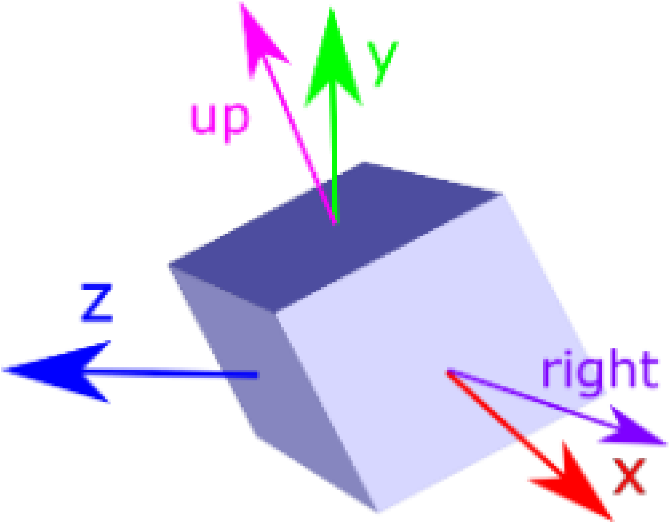


Figure 21: A box transformed into a rotated basis

5.2.4.3.1 Oct-encoded normal vectors

If `NORMAL_UP` and `NORMAL_RIGHT` are not defined for an instance, its orientation may be stored as oct-encoded normals in `NORMAL_UP_OCT32P` and `NORMAL_RIGHT_OCT32P`. These define `up` and `right` using the oct-encoding described in *A Survey of Efficient Representations of Independent Unit Vectors*. Oct-encoded values are stored in unsigned, unnormalized range (`[0, 65535]`) and then mapped to a signed normalized range (`[-1.0, 1.0]`) at runtime.

An implementation for encoding and decoding these unit vectors can be found in Cesium's AttributeCompression module.

5.2.4.3.2 Default orientation

If `NORMAL_UP` and `NORMAL_RIGHT` or `NORMAL_UP_OCT32P` and `NORMAL_RIGHT_OCT32P` are not present, the instance will not have a custom orientation. If `EAST_NORTH_UP` is `true`, the instance is assumed to be on the `WGS84` ellipsoid and its orientation will default to the `east/north/up` reference frame at its cartographic position. This is suitable for instanced models such as trees whose orientation is always facing up from their position on the ellipsoid's surface.

5.2.4.4 Instance position

`POSITION` defines the location for an instance before any tile transforms are applied.

5.2.4.4.1 RTC_CENTER

Positions may be defined relative-to-center for high-precision rendering, see Precisions, Precisions. If defined, `RTC_CENTER` specifies the center position and all instance positions are treated as relative to this value.

5.2.4.4.2 Quantized positions

If POSITION is not defined for an instance, its position may be stored in POSITION_QUANTIZED, which defines the instance position relative to the quantized volume. If neither POSITION or POSITION_QUANTIZED are defined, the instance will not be created.

A quantized volume is defined by offset and scale to map quantized positions into local space, as shown in the following figure:

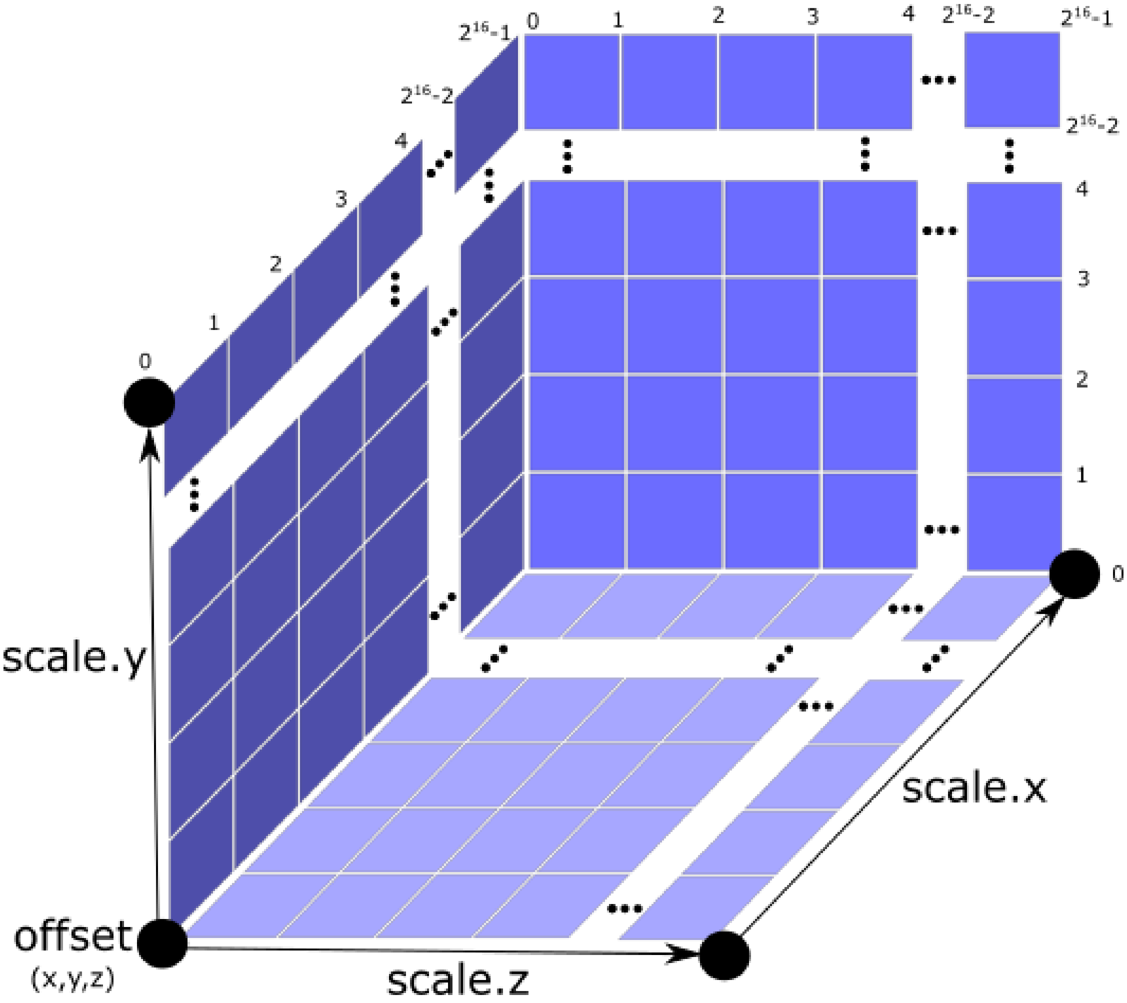


Figure 22: A quantized volume

offset is stored in the global semantic QUANTIZED_VOLUME_OFFSET, and scale is stored in the global semantic QUANTIZED_VOLUME_SCALE. If those global semantics are not defined, POSITION_QUANTIZED cannot be used.

Quantized positions can be mapped to local space using the following formula:

```
POSITION = POSITION_QUANTIZED * QUANTIZED_VOLUME_SCALE / 65535.0 +
QUANTIZED_VOLUME_OFFSET
```

5.2.4.5 Instance scaling

Scaling can be applied to instances using the `SCALE` and `SCALE_NON_UNIFORM` semantics. `SCALE` applies a uniform scale along all axes, and `SCALE_NON_UNIFORM` applies scaling to the x, y, and z axes independently.

5.2.4.6 Examples

These examples show how to generate JSON and binary buffers for the Feature Table.

5.2.4.6.1 Positions only

In this minimal example, we place four instances on the corners of a unit length square with the default orientation:

```
var featureTableJSON = {
    INSTANCES_LENGTH : 4,
    POSITION : {
        byteOffset : 0
    }
};

var featureTableBinary = new Buffer(new Float32Array([
    0.0, 0.0, 0.0,
    1.0, 0.0, 0.0,
    0.0, 0.0, 1.0,
    1.0, 0.0, 1.0
]).buffer);
```

5.2.4.6.2 Quantized positions and oct-encoded normals

In this example, the four instances will be placed with an orientation `up` of `[0.0, 1.0, 0.0]` and `right` of `[1.0, 0.0, 0.0]` in oct-encoded format and they will be placed on the corners of a quantized volume that spans from `-250.0` to `250.0` units in the `x` and `z` directions:

```
var featureTableJSON = {
    INSTANCES_LENGTH : 4,
    QUANTIZED_VOLUME_OFFSET : [-250.0, 0.0, -250.0],
    QUANTIZED_VOLUME_SCALE : [500.0, 0.0, 500.0],
    POSITION_QUANTIZED : {
        byteOffset : 0
    },
    NORMAL_UP_OCT32P : {
        byteOffset : 24
    },
    NORMAL_RIGHT_OCT32P : {
        byteOffset : 40
    }
};
```

```
var positionQuantizedBinary = new Buffer(new Uint16Array([
    0, 0, 0,
    65535, 0, 0,
    0, 0, 65535,
    65535, 0, 65535
]).buffer);

var normalUpOct32PBinary = new Buffer(new Uint16Array([
    32768, 65535,
    32768, 65535,
    32768, 65535,
    32768, 65535
]).buffer);

var normalRightOct32PBinary = new Buffer(new Uint16Array([
    65535, 32768,
    65535, 32768,
    65535, 32768,
    65535, 32768
]).buffer);

var featureTableBinary = Buffer.concat([positionQuantizedBinary,
normalUpOct32PBinary, normalRightOct32PBinary]);
```

5.2.5 Batch Table

Contains metadata organized by `batchId` that can be used for declarative styling. See the Batch Table reference for more information.

5.2.6 glTF

Instanced 3D Model uses glTF 2.0 for model data.

The glTF asset to be instanced is stored after the Feature Table and Batch Table. It may embed all of its geometry, texture, and animations, or it may refer to external sources for some or all of these data.

`header.gltfFormat` determines the format of the glTF field

- When the value of `header.gltfFormat` is `0`, the glTF field is a UTF-8 string, which contains a uri of the glTF or binary glTF model content.
- When the value of `header.gltfFormat` is `1`, the glTF field is a binary blob containing binary glTF.

In either case, `header.gltfByteLength` contains the length of the glTF field in bytes.

5.2.6.1 Coordinate system

By default glTFs use a right handed coordinate system where the *y*-axis is up. For consistency with the *z*-up coordinate system of 3D Tiles, glTFs must be transformed at runtime. See coordinate reference system for more details.

5.2.7 File extension and MIME type

Instanced 3D models tiles use the `.i3dm` extension and `application/octet-stream` MIME type.

An explicit file extension is optional. Valid implementations may ignore it and identify a content's format by the `magic` field in its header.

5.3 Point Cloud

5.3.1 Overview

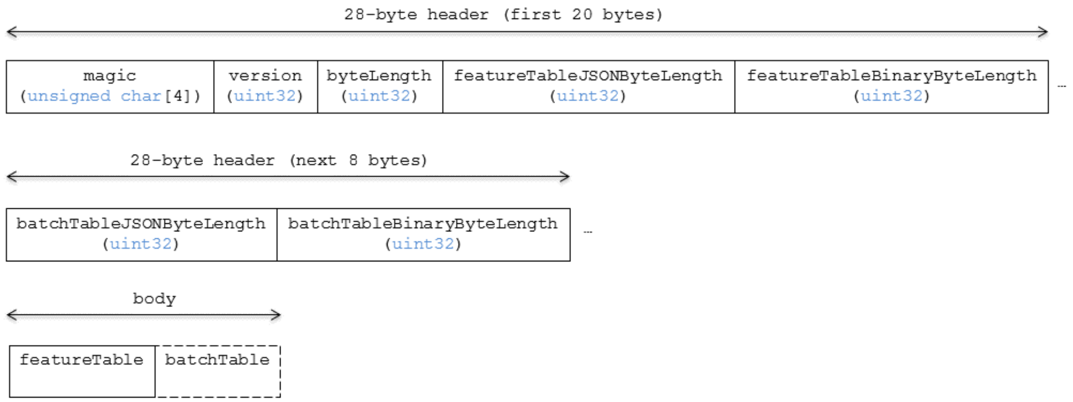
The *Point Cloud* tile format enables efficient streaming of massive point clouds for 3D visualization. Each point is defined by a position and by optional properties used to define its appearance, such as color and normal, as well as optional properties that define application-specific metadata.

Using 3D Tiles terminology, each point is a *feature*.

A Point Cloud tile is a binary blob in little endian.

5.3.2 Layout

A tile is composed of a header section immediately followed by a body section. The following figure shows the Point Cloud layout (dashes indicate optional fields):


28-byte header (first 20 bytes)
magic (unsigned char[4])
version (uint32)
byteLength (uint32)
featureTableJSONByteLength (uint32)
featureTableBinaryByteLength (uint32)
...
28-byte header (next 8 bytes)
batchTableJSONByteLength (uint32)
batchTableBinaryByteLength (uint32)
...
body
featureTable
batchTable

5.3.2.1 Padding

A tile's `byteLength` must be aligned to an 8-byte boundary. The contained Feature Table and Batch Table must conform to their respective padding requirement.

5.3.3 Header

The 28-byte header contains the following fields:

Field name	Data type	Description
`magic`	4-byte ANSI string	`"pnts"`. This can be used to identify the content as a Point Cloud tile.
`version`	`uint32`	The version of the Point Cloud format. It is currently `1`.
`byteLength`	`uint32`	The length of the entire tile, including the header, in bytes.
`featureTableJSONByteLength`	`uint32`	The length of the Feature Table JSON section in bytes.
`featureTableBinaryByteLength`	`uint32`	The length of the Feature Table binary section in bytes.
`batchTableJSONByteLength`	`uint32`	The length of the Batch Table JSON section in bytes. Zero indicates that there is no Batch Table.
`batchTableBinaryByteLength`	`uint32`	The length of the Batch Table binary section in bytes. If `batchTableJSONByteLength` is zero, this will also be zero.

The body section immediately follows the header section, and is composed of a `Feature Table` and `Batch Table`.

5.3.4 Feature Table

Contains per-tile and per-point values that define where and how to render points. More information is available in the Feature Table specification.

5.3.4.1 Property reference

5.3.4.1.1 Point Cloud Feature Table

A set of Point Cloud semantics that contains values defining the position and appearance properties for points in a tile.

Properties

	Type	Description	Required

extensions	`object`	Dictionary object with extension-specific objects.	No
extras	`any`	Application-specific data.	No
POSITION	`object`		No
POSITION_QUANTIZED	`object`		No
RGBA	`object`		No
RGB	`object`		No
RGB565	`object`		No
NORMAL	`object`		No
NORMAL_OCT16P	`object`		No
BATCH_ID	`object`		No
POINTS_LENGTH	`object`		✓ Yes
RTC_CENTER	`object`		No
QUANTIZED_VOLUME_OFFSET	`object`		No
QUANTIZED_VOLUME_SCALE	`object`		No
CONSTANT_RGBA	`object`		No
BATCH_LENGTH	`object`		No

Additional properties are not allowed.

- **JSON schema**: pnts.featureTable.schema.json

5.3.4.1.1.1 point.cloud.feature.table.extensions

Dictionary object with extension-specific objects.

- **Type**: `object`
- **Required**: No
- **Type of each property**: Extension

5.3.4.1.1.2 point.cloud.feature.table.extras

Application-specific data.

- **Type**: `any`
- **Required**: No

5.3.4.1.1.3 point.cloud.feature.table.POSITION

- **Type**: `object`
- **Required**: No

5.3.4.1.1.4 point.cloud.feature.table.POSITION_QUANTIZED

- **Type**: `object`
- **Required**: No

5.3.4.1.1.5 point.cloud.feature.table.RGBA

- **Type**: `object`
- **Required**: No

5.3.4.1.1.6 point.cloud.feature.table.RGB

- **Type**: `object`
- **Required**: No

5.3.4.1.1.7 point.cloud.feature.table.RGB565

- **Type**: `object`
- **Required**: No

5.3.4.1.1.8 point.cloud.feature.table.NORMAL

- **Type**: `object`
- **Required**: No

5.3.4.1.1.9 point.cloud.feature.table.NORMAL_OCT16P

- **Type**: `object`
- **Required**: No

5.3.4.1.1.10 point.cloud.feature.table.BATCH_ID

- **Type**: `object`
- **Required**: No

5.3.4.1.1.11 point.cloud.feature.table.POINTS_LENGTH ✓

- **Type**: `object`
- **Required**: Yes

5.3.4.1.1.12 point.cloud.feature.table.RTC_CENTER

- **Type**: `object`
- **Required**: No

5.3.4.1.1.13 point.cloud.feature.table.QUANTIZED_VOLUME_OFFSET

- **Type**: `object`
- **Required**: No

5.3.4.1.1.14 point.cloud.feature.table.QUANTIZED_VOLUME_SCALE

- **Type**: `object`
- **Required**: No

5.3.4.1.1.15 point.cloud.feature.table.CONSTANT_RGBA

- **Type**: `object`
- **Required**: No

5.3.4.1.1.16 point.cloud.feature.table.BATCH_LENGTH

- **Type**: `object`

- **Required**: No

5.3.4.2 Semantics

5.3.4.2.1 Point semantics

These semantics map to an array of feature values that define each point. The length of these arrays must be the same for all semantics and is equal to the number of points. The value for each point semantic must be a reference to the Feature Table binary body; they cannot be embedded in the Feature Table JSON header.

If a semantic has a dependency on another semantic, that semantic must be defined. If both `POSITION` and `POSITION_QUANTIZED` are defined for a point, the higher precision `POSITION` will be used. If both `NORMAL` and `NORMAL_OCT16P` are defined for a point, the higher precision `NORMAL` will be used.

Semantic	Data Type	Description	Required
`POSITION`	`float32[3]`	A 3-component array of numbers containing x, y, and z Cartesian coordinates for the position of the point.	✓ Yes, unless `POSITION_QUANTIZED` is defined.
`POSITION_QUANTIZED`	`uint16[3]`	A 3-component array of numbers containing x, y, and z in quantized Cartesian coordinates for the position of the point.	✓ Yes, unless `POSITION` is defined.
`RGBA`	`uint8[4]`	A 4-component array of values containing the `RGBA` color of the point.	✗ No.
`RGB`	`uint8[3]`	A 3-component array of values containing the `RGB` color of the point.	✗ No.
`RGB565`	`uint16`	A lossy compressed color format that packs the `RGB` color into 16 bits, providing 5 bits for red, 6 bits for green, and 5 bits for blue.	✗ No.
`NORMAL`	`float32[3]`	A unit vector defining the normal of the point.	✗ No.
`NORMAL_OCT16P`	`uint8[2]`	An oct-encoded unit vector with 16 bits of precision defining the normal of the point.	✗ No.
`BATCH_ID`	`uint8`, `uint16`	The `batchId` of the point that can be used to retrieve	✗ No.

	(default), or `uint32`	metadata from the `Batch Table`.	

5.3.4.2.2 Global semantics

These semantics define global properties for all points.

Semantic	Data Type	Description	Required
`POINTS_LENGTH`	`uint32`	The number of points to render. The length of each array value for a point semantic should be equal to this.	✓ Yes.
`RTC_CENTER`	`float32[3]`	A 3-component array of numbers defining the center position when point positions are defined relative-to-center.	✗ No.
`QUANTIZED_VOLUME_OFFSET`	`float32[3]`	A 3-component array of numbers defining the offset for the quantized volume.	✗ No, unless `POSITION_QUANTIZED` is defined.
`QUANTIZED_VOLUME_SCALE`	`float32[3]`	A 3-component array of numbers	✗ No, unless `POSITION_QUANTIZED` is defined.

		defining the scale for the quantized volume.	
`CONSTANT_RGBA`	`uint8[4]`	A 4-component array of values defining a constant `RGBA` color for all points in the tile.	✗ No.
`BATCH_LENGTH`	`uint32`	The number of unique `BATCH_ID` values.	✗ No, unless `BATCH_ID` is defined.

5.3.4.3 Point positions

`POSITION` defines the position for a point before any tileset transforms are applied.

5.3.4.3.1 Coordinate reference system (CRS)

3D Tiles local coordinate systems use a right-handed 3-axis (x, y, z) Cartesian coordinate system; that is, the cross product of *x* and *y* yields *z*. 3D Tiles defines the *z* axis as up for local Cartesian coordinate systems (also see coordinate reference system).

5.3.4.3.2 RTC_CENTER

Positions may be defined relative-to-center for high-precision rendering, see Precisions, Precisions. If defined, `RTC_CENTER` specifies the center position and all point positions are treated as relative to this value.

5.3.4.3.3 Quantized positions

If `POSITION` is not defined, positions may be stored in `POSITION_QUANTIZED`, which defines point positions relative to the quantized volume. If neither `POSITION` nor `POSITION_QUANTIZED` is defined, the tile does not need to be rendered.

A quantized volume is defined by `offset` and `scale` to map quantized positions to a position in local space. The following figure shows a quantized volume based on `offset` and `scale`:

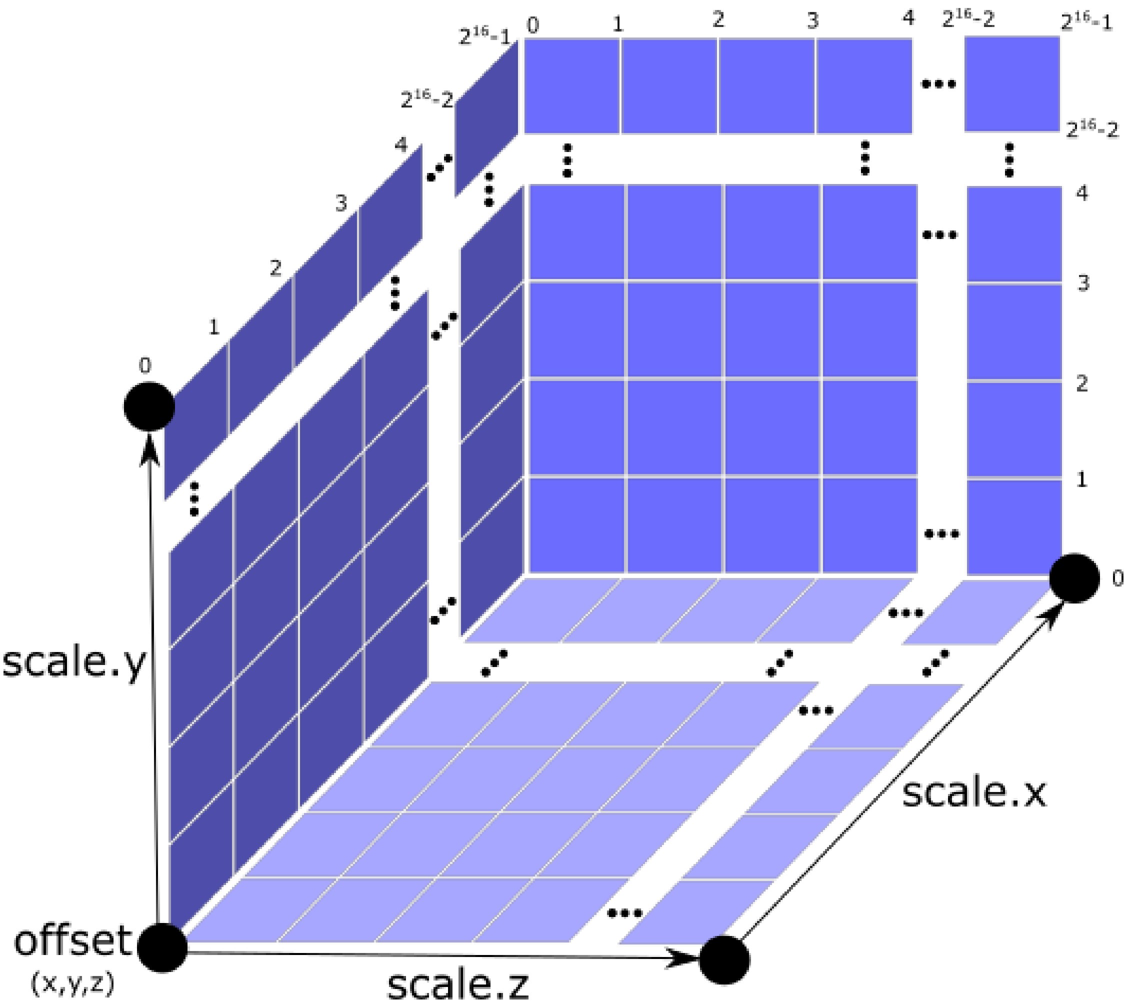


Figure 23: A quantized volume

`offset` is stored in the global semantic `QUANTIZED_VOLUME_OFFSET`, and `scale` is stored in the global semantic `QUANTIZED_VOLUME_SCALE`. If those global semantics are not defined, `POSITION_QUANTIZED` cannot be used.

Quantized positions can be mapped to local space using the following formula:

```
POSITION = POSITION_QUANTIZED * QUANTIZED_VOLUME_SCALE / 65535.0 +
QUANTIZED_VOLUME_OFFSET
```

5.3.4.4 Point colors

If more than one color semantic is defined, the precedence order is `RGBA`, `RGB`, `RGB565`, then `CONSTANT_RGBA`. For example, if a tile's Feature Table contains both `RGBA` and `CONSTANT_RGBA` properties, the runtime would render with per-point colors using `RGBA`.

If no color semantics are defined, the runtime is free to color points using an application-specific default color.

In any case, 3D Tiles Styling may be used to change the final rendered color and other visual properties at runtime.

5.3.4.5 Point normals

Per-point normals are an optional property that can help improve the visual quality of points by enabling lighting, hidden surface removal, and other rendering techniques. The normals will be transformed using the inverse transpose of the tileset transform.

5.3.4.5.1 Oct-encoded normal vectors

Oct-encoding is described in *A Survey of Efficient Representations of Independent Unit Vectors*. Oct-encoded values are stored in unsigned, unnormalized range (`[0, 255]`) and then mapped to a signed normalized range (`[-1.0, 1.0]`) at runtime.

An implementation for encoding and decoding these unit vectors can be found in Cesium's AttributeCompression module.

5.3.4.6 Batched points

Points that make up distinct features of the Point Cloud may be batched together using the `BATCH_ID` semantic. For example, the points that make up a door in a house would all be assigned the same `BATCH_ID`, whereas points that make up a window would be assigned a different `BATCH_ID`. This is useful for per-object picking and storing application-specific metadata for declarative styling and application-specific use cases such as populating a UI or issuing a REST API request on a per-object instead of per-point basis.

The `BATCH_ID` semantic may have a `componentType` of `UNSIGNED_BYTE`, `UNSIGNED_SHORT`, or `UNSIGNED_INT`. When `componentType` is not present, `UNSIGNED_SHORT` is used. The global semantic `BATCH_LENGTH` defines the number of unique `batchId` values, similar to the `batchLength` field in the Batched 3D Model header.

5.3.4.7 Examples

This section is non-normative

These examples show how to generate JSON and binary buffers for the Feature Table.

5.3.4.7.1 Positions only

This minimal example has four points on the corners of a unit length square:

```
var featureTableJSON = {
    POINTS_LENGTH : 4,
    POSITION : {
        byteOffset : 0
    }
};

var featureTableBinary = new Buffer(new Float32Array([
    0.0, 0.0, 0.0,
    1.0, 0.0, 0.0,
    0.0, 0.0, 1.0,
    1.0, 0.0, 1.0
]).buffer);
```

5.3.4.7.2 Positions and colors

The following example has four points (red, green, blue, and yellow) above the globe. Their positions are defined relative to center:

```
var featureTableJSON = {
    POINTS_LENGTH : 4,
    RTC_CENTER : [1215013.8, -4736316.7, 4081608.4],
    POSITION : {
        byteOffset : 0
    },
    RGB : {
        byteOffset : 48
    }
};

var positionBinary = new Buffer(new Float32Array([
    0.0, 0.0, 0.0,
    1.0, 0.0, 0.0,
    0.0, 0.0, 1.0,
    1.0, 0.0, 1.0
]).buffer);

var colorBinary = new Buffer(new Uint8Array([
    255, 0, 0,
    0, 255, 0,
    0, 0, 255,
    255, 255, 0,
]).buffer);

var featureTableBinary = Buffer.concat([positionBinary, colorBinary]);
```

5.3.4.7.3 Quantized positions and oct-encoded normals

In this example, the four points will have normals pointing up `[0.0, 1.0, 0.0]` in oct-encoded format, and they will be placed on the corners of a quantized volume that spans from `-250.0` to `250.0` units in the x and z directions:

```
var featureTableJSON = {
    POINTS_LENGTH : 4,
    QUANTIZED_VOLUME_OFFSET : [-250.0, 0.0, -250.0],
    QUANTIZED_VOLUME_SCALE : [500.0, 0.0, 500.0],
    POSITION_QUANTIZED : {
        byteOffset : 0
    },
    NORMAL_OCT16P : {
        byteOffset : 24
    }
};

var positionQuantizedBinary = new Buffer(new Uint16Array([
    0, 0, 0,
    65535, 0, 0,
    0, 0, 65535,
    65535, 0, 65535
]).buffer);

var normalOct16PBinary = new Buffer(new Uint8Array([
    128, 255,
    128, 255,
    128, 255,
    128, 255
]).buffer);

var featureTableBinary = Buffer.concat([positionQuantizedBinary,
normalOct16PBinary]);
```

5.3.4.7.4 Batched points

In this example, the first two points have a `batchId` of 0, and the next two points have a `batchId` of 1. Note that the Batch Table only has two names:

```
var featureTableJSON = {
    POINTS_LENGTH : 4,
    BATCH_LENGTH : 2,
    POSITION : {
        byteOffset : 0
    },
    BATCH_ID : {
        byteOffset : 48,
        componentType : "UNSIGNED_BYTE"
    }
};

var positionBinary = new Buffer(new Float32Array([
    0.0, 0.0, 0.0,
    1.0, 0.0, 0.0,
    0.0, 0.0, 1.0,
    1.0, 0.0, 1.0
]).buffer);

var batchIdBinary = new Buffer(new Uint8Array([
    0,
    0,
    1,
    1
]).buffer);

var featureTableBinary = Buffer.concat([positionBinary, batchIdBinary]);

var batchTableJSON = {
    names : ['object1', 'object2']
};
```

5.3.4.7.5 Per-point properties

In this example, each of the 4 points will have metadata stored in the Batch Table JSON and binary.

```
var featureTableJSON = {
    POINTS_LENGTH : 4,
    POSITION : {
        byteOffset : 0
    }
};

var featureTableBinary = new Buffer(new Float32Array([
    0.0, 0.0, 0.0,
    1.0, 0.0, 0.0,
    0.0, 0.0, 1.0,
    1.0, 0.0, 1.0
]).buffer);

var batchTableJSON = {
    names : ['point1', 'point2', 'point3', 'point4']
};
```

5.3.5 Batch Table

The *Batch Table* contains application-specific metadata, indexable by `batchId`, that can be used for declarative styling and application-specific use cases such as populating a UI or issuing a REST API request.

- If the `BATCH_ID` semantic is defined, the Batch Table stores metadata for each `batchId`, and the length of the Batch Table arrays will equal `BATCH_LENGTH`.
- If the `BATCH_ID` semantic is not defined, then the Batch Table stores per-point metadata, and the length of the Batch Table arrays will equal `POINTS_LENGTH`.

See the Batch Table reference for more information.

5.3.6 File extension and MIME type

Point cloud tiles use the `.pnts` extension and `application/octet-stream` MIME type.

An explicit file extension is optional. Valid implementations may ignore it and identify a content's format by the `magic` field in its header.

5.4 Composite

5.4.1 Overview

The *Composite* tile format enables concatenating tiles of different formats into one tile.

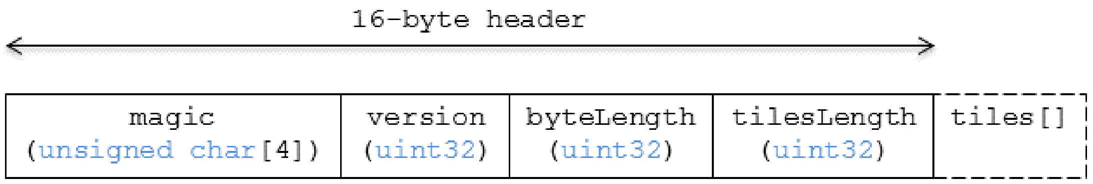
3D Tiles and the Composite tile allow flexibility for streaming heterogeneous datasets. For example, buildings and trees could be stored either in two separate *Batched 3D Model* and *Instanced 3D Model* tiles or, using a *Composite* tile, the tiles can be combined.

Supporting heterogeneous datasets with both inter-tile (separate tiles of different formats that are in the same tileset) and intra-tile (different tile formats that are in the same Composite tile) options allows conversion tools to make trade-offs between number of requests, optimal type-specific subdivision, and how visible/hidden layers are streamed.

A Composite tile is a binary blob in little endian.

5.4.2 Layout

Composite layout (dashes indicate optional fields):



5.4.2.1 Padding

A tile's `byteLength` must be aligned to an 8-byte boundary. All tiles contained in a composite tile must also be aligned to an 8-byte boundary.

5.4.3 Header

The 16-byte header section contains the following fields:

Field name	Data type	Description
`magic`	4-byte ANSI string	`"cmpt"`. This can be used to identify the content as a Composite tile.
`version`	`uint32`	The version of the Composite format. It is currently `1`.
`byteLength`	`uint32`	The length of the entire Composite tile, including this header and each inner tile, in bytes.

`tilesLength`	`uint32`	The number of tiles in the Composite.

5.4.4 Inner tiles

Inner tile fields are stored tightly packed immediately following the header section. The following information describes general characteristics of all tile formats that a Composite tile reader might exploit to find the boundaries of the inner tiles:

- Each tile starts with a 4-byte ANSI string, `magic`, that can be used to determine the tile format for further parsing. See tile format specifications for a list of possible formats. Composite tiles can contain Composite tiles.
- Each tile's header contains a `uint32` `byteLength`, which defines the length of the inner tile, including its header, in bytes. This can be used to traverse the inner tiles.
- For any tile format's version 1, the first 12 bytes of all tiles is the following fields:

Field name	Data type	Description
`magic`	4-byte ANSI string	Indicates the tile format
`version`	`uint32`	`1`
`byteLength`	`uint32`	Length, in bytes, of the entire tile.

Refer to the spec for each tile format for more details.

5.4.5 File extension and MIME type

Composite tiles use the `.cmpt` extension and `application/octet-stream` MIME type.

An explicit file extension is optional. Valid implementations may ignore it and identify a content's format by the `magic` field in its header.

6 Declarative styling specification

3D Tiles includes concise declarative styling defined with JSON and expressions written in a small subset of JavaScript augmented for styling.

Styles define how a featured is displayed, for example `show` and `color` (RGB and translucency), using an expression based on a feature's properties.

The following example colors features with a temperature above 90 as red and the others as white.

```
{
    "color" : "(${Temperature} > 90) ? color('red') : color('white')"
}
```

6.1 Overview

3D Tiles styles provide concise declarative styling of tileset features. A style defines expressions to evaluate the display of a feature, for example *color* (RGB and translucency) and *show* properties, often based on the feature's properties stored in the tile's *Batch Table*.

While a style may be created for and reference properties of a tileset, a style is independent of a tileset, such that any style can be applied to any tileset.

Styles are defined with JSON and expressions written in a small subset of JavaScript augmented for styling. Additionally, the styling language provides a set of built-in functions to support common math operations.

The following example assigns a color based on building height.

```
{
    "show" : "${Area} > 0",
    "color" : {
        "conditions" : [
            ["${Height} < 60", "color('#13293D')"],
            ["${Height} < 120", "color('#1B98E0')"],
            ["true", "color('#E8F1F2', 0.5)"]
        ]
    }
}
```

6.2 Concepts

6.2.1 Styling features

Visual properties available for styling features are the *show* property, the assigned expression of which will evaluate to a boolean that determines if the feature is visible, and the *color* property, the assigned expression of which will evaluate to a *Color* object (RGB and translucency) which determines the displayed color of a feature.

The following style assigns the default show and color properties to each feature:

```
{
    "show" : "true",
    "color" : "color('#ffffff')"
}
```

Instead of showing all features, *show* can be an expression dependent on a feature's properties, for example, the following expression will show only features in the 19341 zip code:

```
{
    "show" : "${ZipCode} === '19341'"
}
```

show can also be used for more complex queries; for example, here a compound condition and regular expression are used to show only features whose county starts with *'Chest'* and whose year built is greater than or equal to 1970:

```
{
    "show" : "(regExp('^Chest').test(${County})) && (${YearBuilt} >= 1970)"
}
```

Colors can also be defined by expressions dependent on a feature's properties. For example, the following expression colors features with a temperature above 90 as red and the others as white:

```
{
    "color" : "(${Temperature} > 90) ? color('red') : color('white')"
}
```

The color's alpha component defines the feature's opacity. For example, the following sets the feature's RGB color components from the feature's properties and makes features with volume greater than 100 transparent:

```
{
   "color" : "rgba(${red}, ${green}, ${blue}, (${volume} > 100 ? 0.5 : 1.0))"
}
```

6.2.2 Conditions

In addition to a string containing an expression, *color* and *show* can be an array defining a series of conditions (similar to *if...else* statements). Conditions can, for example, be used to make color maps and color ramps with any type of inclusive/exclusive intervals.

For example, the following expression maps an ID property to colors. Conditions are evaluated in order, so if *${id}* is not *'1'* or *'2'*, the *"true"* condition returns white. If no conditions are met, the color of the feature will be *undefined*:

```
{
    "color" : {
        "conditions" : [
            ["${id} === '1'", "color('#FF0000')"],
            ["${id} === '2'", "color('#00FF00')"],
            ["true", "color('#FFFFFF')"]
        ]
    }
}
```

The next example shows how to use conditions to create a color ramp using intervals with an inclusive lower bound and exclusive upper bound:

```
"color" : {
    "conditions" : [
        ["(${Height} >= 1.0)  && (${Height} < 10.0)", "color('#FF00FF')"],
        ["(${Height} >= 10.0) && (${Height} < 30.0)", "color('#FF0000')"],
        ["(${Height} >= 30.0) && (${Height} < 50.0)", "color('#FFFF00')"],
        ["(${Height} >= 50.0) && (${Height} < 70.0)", "color('#00FF00')"],
        ["(${Height} >= 70.0) && (${Height} < 100.0)", "color('#00FFFF')"],
        ["(${Height} >= 100.0)", "color('#0000FF')"]
    ]
}
```

Since conditions are evaluated in order, the above can be written more concisely as the following:

```
"color" : {
    "conditions" : [
        ["(${Height} >= 100.0)", "color('#0000FF')"],
        ["(${Height} >= 70.0)", "color('#00FFFF')"],
        ["(${Height} >= 50.0)", "color('#00FF00')"],
        ["(${Height} >= 30.0)", "color('#FFFF00')"],
        ["(${Height} >= 10.0)", "color('#FF0000')"],
        ["(${Height} >= 1.0)", "color('#FF00FF')"]
    ]
}
```

6.2.3 Defining variables

Commonly used expressions may be stored in a *defines* object with a variable name as a key. If a variable references the name of a defined expression, it is replaced with the result of the referenced evaluated expression:

```
{
    "defines" : {
        "NewHeight" : "clamp((${Height} - 0.5) / 2.0, 1.0, 255.0)",
        "HeightColor" : "rgb(${Height}, ${Height}, ${Height})"
    },
    "color" : {
        "conditions" : [
            ["(${NewHeight} >= 100.0)", "color('#0000FF') * ${HeightColor}"],
            ["(${NewHeight} >= 50.0)", "color('#00FF00') * ${HeightColor}"],
            ["(${NewHeight} >= 1.0)", "color('#FF0000') * ${HeightColor}"]
        ]
    },
    "show" : "${NewHeight} < 200.0"
}
```

A define expression may not reference other defines; however, it may reference feature properties with the same name. In the style below a feature of height 150 gets the color red:

```
{
    "defines" : {
        "Height" : "${Height}/2.0}",
    },
    "color" : {
        "conditions" : [
            ["(${Height} >= 100.0)", "color('#0000FF')"],
            ["(${Height} >= 1.0)", "color('#FF0000')"]
        ]
    }
}
```

6.2.4 Meta property

Non-visual properties of a feature can be defined using the *meta* property. For example, the following sets a *description* meta property to a string containing the feature name:

```
{
    "meta" : {
        "description" : "'Hello, ${featureName}.'"
    }
}
```

A meta property expression can evaluate to any type. For example:

```
{
    "meta" : {
        "featureColor" : "rgb(${red}, ${green}, ${blue})",
        "featureVolume" : "${height} * ${width} * ${depth}"
    }
}
```

6.3 Property reference

expression

A valid 3D Tiles style expression.

---

boolean expression

A boolean or string with a 3D Tiles style expression that evaluates to a boolean.

---

color expression

3D Tiles style expression that evaluates to a Color.

#### number expression

3D Tiles style expression that evaluates to a
number.

conditions

A series of conditions evaluated in order, like a series of if...else statements that result in an expression being evaluated.

Properties

	Type	Description	Required
conditions	*array [ ]*	A series of boolean conditions evaluated in order. For the first one that evaluates to true, its value, the 'result' (which is also an expression), is evaluated and returned. Result expressions must all be the same type. If no condition evaluates to true, the result is *undefined*. When conditions is *undefined*, *null*, or an empty object, the result is *undefined*.	No

Additional properties are not allowed.

- **JSON schema**: *style.conditions.schema.json*

conditions.conditions

A series of boolean conditions evaluated in order. For the first one that evaluates to true, its value, the 'result' (which is also an expression), is evaluated and returned. Result expressions must all be the same type. If no condition evaluates to true, the result is *undefined*. When conditions is *undefined*, *null*, or an empty object, the result is *undefined*.

- **Type**: *array [ ]*
- **Required**: No

condition

An expression evaluated as the result of a condition being true. An array of two expressions. If the first expression is evaluated and the result is *true*, then the second expression is evaluated and returned as the result of the condition.

definesProperty

A property name and the expression to be evaluated for the value of that property.

meta

A series of property names and the expression to evaluate for the value of each property.

Additional properties are allowed.

- **JSON schema**: *style.meta.schema.json*

#### metaProperty

A property name and the expression to be evaluated for the value of that property.

style

A 3D Tiles style.

Properties

	Type	Description	Required
defines	*object*	Additional expressions that may be referenced throughout the style. If a variable references a define, it gets the result of the define's evaluated expression.	No
show	*boolean*, *string*	Determines if a feature should be shown.	No, default: *true*
color	*string*	Determines the color blended with the feature's intrinsic color.	No, default: *"Color('#FFFFFF')"*
meta	*object*	Determines the values of non-visual properties of the feature.	No

Additional properties are not allowed.

- **JSON schema**: *style.schema.json*

style.defines

Additional expressions that may be referenced throughout the style. If a variable references a define, it gets the result of the define's evaluated expression.

- **Type**: *object*
- **Required**: No
- **Type of each property**: *string*

style.show

Determines if a feature should be shown.

- **Type**: *boolean*, *string*
- **Required**: No, default: *true*
- **Allowed values**:

style.color

Determines the color blended with the feature's intrinsic color.

- **Type**: *string*
- **Required**: No, default: *"Color('#FFFFFF')"*
- **Allowed values**:

style.meta

Determines the values of non-visual properties of the feature.

- **Type**: *object*
- **Required**: No
- **Type of each property**: *string*

Point Cloud Style

A 3D Tiles style with additional properties for Point Clouds.

Properties

	Type	Description	Required
defines	*object*	Additional expressions that may be referenced throughout the style. If a variable references a define, it gets the result of the define's evaluated expression.	No
show	*boolean*, *string*	Determines if a feature should be shown.	No, default: *true*
color	*string*	Determines the color blended with the feature's	No, default: *"Color('#FFFFFF')"*

		intrinsic color.	
meta	`object`	Determines the values of non-visual properties of the feature.	No
pointSize	`number`,`string`	Determines the size of the points in pixels.	No, default: `1`

Additional properties are not allowed.

- **JSON schema**: *pnts.style.schema.json*

point.cloud.style.defines

Additional expressions that may be referenced throughout the style. If a variable references a define, it gets the result of the define's evaluated expression.

- **Type**: `object`
- **Required**: No
- **Type of each property**: `string`

point.cloud.style.show

Determines if a feature should be shown.

- **Type**: `boolean`,`string`
- **Required**: No, default: `true`
- **Allowed values**:

point.cloud.style.color

Determines the color blended with the feature's intrinsic color.

- **Type**: `string`
- **Required**: No, default: `"Color('#FFFFFF')"`
- **Allowed values**:

point.cloud.style.meta

Determines the values of non-visual properties of the feature.

- **Type**: `object`
- **Required**: No

- **Type of each property**: `string`

point.cloud.style.pointSize

Determines the size of the points in pixels.

- **Type**: `number`, `string`
- **Required**: No, default: `1`
- **Allowed values**:

6.4 Expressions

The language for expressions is a small subset of JavaScript (*EMCAScript 5*), plus native vector and regular expression types and access to tileset feature properties in the form of readonly variables.

Implementation Note: Cesium uses the *jsep* JavaScript expression parser library to parse style expressions.

6.4.1 Semantics

Dot notation is used to access properties by name, e.g., `building.name`.

Bracket notation (`[]`) is also used to access properties, e.g., `building['name']`, or arrays, e.g., `temperatures[1]`.

Functions are called with parenthesis (`()`) and comma-separated arguments, e.g., (`isNaN(0.0)`, `color('cyan', 0.5)`).

6.4.2 Operators

The following operators are supported with the same semantics and precedence as JavaScript.

- Unary: `+`, `-`, `!`
- Not supported: `~`
- Binary: `||`, `&&`, `===`, `!==`, `<`, `>`, `<=`, `>=`, `+`, `-`, `*`, `/`, `%`, `=~`, `!~`
- Not supported: `|`, `^`, `&`, `<<`, `>>`, and `>>>`
- Ternary: `? :`

`(` and `)` are also supported for grouping expressions for clarity and precedence.

Logical `||` and `&&` implement short-circuiting; `true || expression` does not evaluate the right expression, and `false && expression` does not evaluate the right expression.

Similarly, `true ? leftExpression : rightExpression` only executes the left expression, and `false ? leftExpression : rightExpression` only executes the right expression.

6.4.3 Types

The following types are supported: * *Boolean* * *Null* * *Undefined* * *Number* * *String* * *Array* * *vec2* * *vec3* * *vec4* * *RegExp*

All of the types except *vec2*, *vec3*, *vec4*, and *RegExp* have the same syntax and runtime behavior as JavaScript. *vec2*, *vec3*, and *vec4* are derived from GLSL vectors and behave similarly to JavaScript *Object* (see the *Vector section*). Colors derive from *CSS3 Colors* and are implemented as *vec4*. *RegExp* is derived from JavaScript and described in the *RegExp section*.

Example expressions for different types include the following: * *true*, *false* * *null* * *undefined* * *1.0*, *NaN*, *Infinity* * *'Cesium'*, *"Cesium"* * *[0, 1, 2]* * *vec2(1.0, 2.0)* * *vec3(1.0, 2.0, 3.0)* * *vec4(1.0, 2.0, 3.0, 4.0)* * *color('#00FFFF')* * *regExp('^Chest'))*

Number

As in JavaScript, numbers can be *NaN* or *Infinity*. The following test functions are supported: * *isNaN(testValue : Number) : Boolean* * *isFinite(testValue : Number) : Boolean*

Vector

The styling language includes 2, 3, and 4 component floating-point vector types: *vec2*, *vec3*, and *vec4*. Vector constructors share the same rules as GLSL:

vec2

- *vec2(xy : Number)* - initialize each component with the number
- *vec2(x : Number, y : Number)* - initialize with two numbers
- *vec2(xy : vec2)* - initialize with another *vec2*
- *vec2(xyz : vec3)* - drops the third component of a *vec3*
- *vec2(xyzw : vec4)* - drops the third and fourth component of a *vec4*

vec3

- *vec3(xyz : Number)* - initialize each component with the number
- *vec3(x : Number, y : Number, z : Number)* - initialize with three numbers
- *vec3(xyz : vec3)* - initialize with another *vec3*
- *vec3(xyzw : vec4)* - drops the fourth component of a *vec4*
- *vec3(xy : vec2, z : Number)* - initialize with a *vec2* and number
- *vec3(x : Number, yz : vec2)* - initialize with a *vec2* and number

vec4

- *vec4(xyzw : Number)* - initialize each component with the number
- *vec4(x : Number, y : Number, z : Number, w : Number)* - initialize with four numbers
- *vec4(xyzw : vec4)* - initialize with another *vec4*

- *vec4(xy : vec2, z : Number, w : Number)* - initialize with a *vec2* and two numbers
- *vec4(x : Number, yz : vec2, w : Number)* - initialize with a *vec2* and two numbers
- *vec4(x : Number, y : Number, zw : vec2)* - initialize with a *vec2* and two numbers
- *vec4(xyz : vec3, w : Number)* - initialize with a *vec3* and number
- *vec4(x : Number, yzw : vec3)* - initialize with a *vec3* and number

Vector usage

vec2 components may be accessed with * *.x*, *.y* * *.r*, *.g* * *[0]*, *[1]*

vec3 components may be accessed with * *.x*, *.y*, *.z* * *.r*, *.g*, *.b* * *[0]*, *[1]*, *[2]*

vec4 components may be accessed with * *.x*, *.y*, *.z*, *.w* * *.r*, *.g*, *.b*, *.a* * *[0]*, *[1]*, *[2]*, *[3]*

Unlike GLSL, the styling language does not support swizzling. For example, *vec3(1.0).xy* is not supported.

Vectors support the following unary operators: *-*, *+*.

Vectors support the following binary operators by performing component-wise operations: *===*, *!==*, *+*, *-*, ***, */*, and *%*. For example *vec4(1.0) === vec4(1.0)* is true since the *x*, *y*, *z*, and *w* components are equal. Operators are essentially overloaded for *vec2*, *vec3*, and *vec4*.

vec2, *vec3*, and *vec4* have a *toString* function for explicit (and implicit) conversion to strings in the format *'(x, y)'*, *'(x, y, z)'*, and *'(x, y, z, w)'*. * *toString() : String*

vec2, *vec3*, and *vec4* do not expose any other functions or a *prototype* object.

Color

Colors are implemented as *vec4* and are created with one of the following functions: * *color()* * *color(keyword : String, [alpha : Number])* * *color(6-digit-hex : String, [alpha : Number])* * *color(3-digit-hex : String, [alpha : Number])* * *rgb(red : Number, green : Number, blue : Number)* * *rgba(red : Number, green : Number, blue : Number, alpha : Number)* * *hsl(hue : Number, saturation : Number, lightness : Number)* * *hsla(hue : Number, saturation : Number, lightness : Number, alpha : Number)*

Calling *color()* with no arguments is the same as calling *color('#FFFFFF')*.

Colors defined by a case-insensitive keyword (e.g., *'cyan'*) or hex rgb are passed as strings to the *color* function. For example: * *color('cyan')* * *color('#00FFFF')* * *color('#0FF')*

These *color* functions have an optional second argument that is an alpha component to define opacity, where *0.0* is fully transparent and *1.0* is fully opaque. For example: * *color('cyan', 0.5)*

Colors defined with decimal RGB or HSL are created with *rgb* and *hsl* functions, respectively, just as in CSS (but with percentage ranges from *0.0* to *1.0* for *0%* to *100%*, respectively). For example: * *rgb(100, 255, 190)* * *hsl(1.0, 0.6, 0.7)*

The range for `rgb` components is `0` to `255`, inclusive. For `hsl`, the range for hue, saturation, and lightness is `0.0` to `1.0`, inclusive.

Colors defined with `rgba` or `hsla` have a fourth argument that is an alpha component to define opacity, where `0.0` is fully transparent and `1.0` is fully opaque. For example: * `rgba(100, 255, 190, 0.25)` * `hsla(1.0, 0.6, 0.7, 0.75)`

Colors are equivalent to the `vec4` type and share the same functions, operators, and component accessors. Color components are stored in the range `0.0` to `1.0`.

For example: * `color('red').x`, `color('red').r`, and `color('red')[0]` all evaluate to `1.0`. * `color('red').toString()` evaluates to `(1.0, 0.0, 0.0, 1.0)` * `color('red') * vec4(0.5)` is equivalent to `vec4(0.5, 0.0, 0.0, 0.5)`

RegExp

Regular expressions are created with the following functions, which behave like the JavaScript RegExp constructor: * `regExp()` * `regExp(pattern : String, [flags : String])`

Calling `regExp()` with no arguments is the same as calling `regExp('(?:)')`.

If specified, `flags` can have any combination of the following values:

- `g` - global match
- `i` - ignore case
- `m` - multiline
- `u` - unicode
- `y`- sticky

Regular expressions support these functions: * `test(string : String) : Boolean` - Tests the specified string for a match. * `exec(string : String) : String` - Executes a search for a match in the specified string. If the search succeeds, it returns the first instance of a captured `String`. If the search fails, it returns `null`.

For example:

```
{
    "Name" : "Building 1"
}
```

```
regExp('a').test('abc') === true
regExp('a(.)', 'i').exec('Abc') === 'b'
regExp('Building\s(\d)').exec(${Name}) === '1'
```

Regular expressions have a `toString` function for explicit (and implicit) conversion to strings in the format `'pattern'`: * `toString() : String`

Regular expressions do not expose any other functions or a `prototype` object.

The operators =~ and *!~* are overloaded for regular expressions. The =~ operator matches the behavior of the `test` function, and tests the specified string for a match. It returns *true* if one is found, and *false* if not found. The *!~* operator is the inverse of the =~ operator. It returns *true* if no matches are found, and *false* if a match is found. Both operators are commutative.

For example, the following expressions all evaluate to true:

```
regExp('a') =~ 'abc'
'abc' =~ regExp('a')

regExp('a') !~ 'bcd'
'bcd' !~ regExp('a')
```

6.4.4 Operator rules

- Unary operators *+* and *-* operate only on number and vector expressions.
- Unary operator *!* operates only on boolean expressions.
- Binary operators *<*, *<=*, *>*, and *>=* operate only on number expressions.
- Binary operators *||* and *&&* operate only on boolean expressions.
- Binary operator *+* operates on the following expressions:
  - Number expressions
  - Vector expressions of the same type
  - If at least one expressions is a string, the other expression is converted to a string following *String Conversions*, and the operation returns a concatenated string, e.g. *"name" + 10* evaluates to *"name10"*
- Binary operator *-* operates on the following expressions:
  - Number expressions
  - Vector expressions of the same type
- Binary operator *** operates on the following expressions:
  - Number expressions
  - Vector expressions of the same type
  - Mix of number expression and vector expression, e.g. *3 * vec3(1.0)* and *vec2(1.0) * 3*
- Binary operator */* operates on the following expressions:
  - Number expressions
  - Vector expressions of the same type
  - Vector expression followed by number expression, e.g.*vec3(1.0) / 3*
- Binary operator *%* operates on the following expressions:
  - Number expressions
  - Vector expressions of the same type
- Binary equality operators *===* and *!==* operate on any expressions. The operation returns *false* if the expression types do not match.
- Binary *regExp* operators =~ and *!~* require one argument to be a string expression and the other to be a *RegExp* expression.

- Ternary operator *? :* conditional argument must be a boolean expression.

6.4.5 Type conversions

Explicit conversions between primitive types are handled with *Boolean*, *Number*, and *String* functions. * *Boolean(value : Any) : Boolean* * *Number(value : Any) : Number* * *String(value : Any) : String*

For example:

```
Boolean(1) === true
Number('1') === 1
String(1) === '1'
```

Boolean and *Number* follow JavaScript conventions. *String* follows *String Conversions*.

These are essentially casts, not constructor functions.

The styling language does not allow for implicit type conversions, unless stated above. Expressions like *vec3(1.0) === vec4(1.0)* and *"5" < 6* are not valid.

6.4.6 String conversions

vec2, *vec3*, *vec4*, and *RegExp* expressions are converted to strings using their *toString* methods. All other types follow JavaScript conventions.

- *true* - *"true"*
- *false* - *"false"*
- *null* - *"null"*
- *undefined* - *"undefined"*
- *5.0* - *"5"*
- *NaN* - *"NaN"*
- *Infinity* - *"Infinity"*
- *"name"* - *"name"*
- *[0, 1, 2]* - *"[0, 1, 2]"*
- *vec2(1, 2)* - *"(1, 2)"*
- *vec3(1, 2, 3)* - *"(1, 2, 3)"*
- *vec4(1, 2, 3, 4)* - *"(1, 2, 3, 4)"*
- *RegExp('a')* - *"/a/"*

6.4.7 Constants

The following constants are supported by the styling language:

- *Math.PI*
- *Math.E*

PI

The mathematical constant PI, which represents a circle's circumference divided by its diameter, approximately `3.14159`.

```
{
    "show" : "cos(${Angle} + Math.PI) < 0"
}
```

E

Euler's constant and the base of the natural logarithm, approximately `2.71828`.

```
{
    "color" : "color() * pow(Math.E / 2.0, ${Temperature})"
}
```

6.4.8 Variables

Variables are used to retrieve the property values of individual features in a tileset. Variables are identified using the ES 6 (*ECMAScript 2015*) template literal syntax, i.e., `${feature.identifier}` or `${feature['identifier']}`, where the identifier is the case-sensitive property name. `feature` is implicit and can be omitted in most cases.

Variables can be used anywhere a valid expression is accepted, except inside other variable identifiers. For example, the following is not allowed:

```
${foo[${bar}]}
```

If a feature does not have a property with the specified name, the variable evaluates to `undefined`. Note that the property may also be `null` if `null` was explicitly stored for a property.

Variables may be any of the supported native JavaScript types: * `Boolean` * `Null` * `Undefined` * `Number` * `String` * `Array`

For example:

```
{
    "enabled" : true,
    "description" : null,
    "order" : 1,
    "name" : "Feature name"
}
```

```
${enabled} === true
${description} === null
${order} === 1
${name} === 'Feature name'
```

Additionally, variables originating from vector properties stored in the *Batch Table binary* are treated as vector types:

componentType	variable type
"VEC2"	*vec2*
"VEC3"	*vec3*
"VEC4"	*vec4*

Variables can be used to construct colors or vectors. For example:

```
rgba(${red}, ${green}, ${blue}, ${alpha})
vec4(${temperature})
```

Dot or bracket notation is used to access feature subproperties. For example:

```
{
    "address" : {
        "street" : "Example street",
        "city" : "Example city"
    }
}
```

```
${address.street} === `Example street`
${address['street']} === `Example street`

${address.city} === `Example city`
${address['city']} === `Example city`
```

Bracket notation supports only string literals.

Top-level properties can be accessed with bracket notation by explicitly using the *feature* keyword. For example:

```
{
    "address.street" : "Maple Street",
    "address" : {
        "street" : "Oak Street"
    }
}
```

```
${address.street} === `Oak Street`
${feature.address.street} === `Oak Street`
${feature['address'].street} === `Oak Street`
${feature['address.street']} === `Maple Street`
```

To access a feature named *feature*, use the variable *${feature}*. This is equivalent to accessing *${feature.feature}*

```
{
    "feature" : "building"
}
```

```
${feature} === `building`
${feature.feature} === `building`
```

Variables can also be substituted inside strings defined with backticks, for example:

```
{
    "order" : 1,
    "name" : "Feature name"
}
```

```
`Name is ${name}, order is ${order}`
```

Bracket notation is used to access feature subproperties or arrays. For example:

```
{
    "temperatures" : {
        "scale" : "fahrenheit",
        "values" : [70, 80, 90]
    }
}
```

```
${temperatures['scale']} === 'fahrenheit'
${temperatures.values[0]} === 70
${temperatures['values'][0]} === 70 // Same as (temperatures[values])[0] and
temperatures.values[0]
```

6.4.9 Built-in variables

The prefix `tiles3d_` is reserved for built-in variables. The following built-in variables are supported by the styling language:

- *tiles3d_tileset_time*

tiles3d_tileset_time

Gets the time, in milliseconds, since the tileset was first loaded. This is useful for creating dynamic styles that change with time.

```
{
    "color" : "color() * abs(cos(${Temperature} + ${tiles3d_tileset_time}))"
}
```

6.4.10 Built-in functions

The following built-in functions are supported by the styling language:

- *abs*
- *sqrt*
- *cos*
- *sin*
- *tan*
- *acos*
- *asin*

- *atan*
- *atan2*
- *radians*
- *degrees*
- *sign*
- *floor*
- *ceil*
- *round*
- *exp*
- *log*
- *exp2*
- *log2*
- *fract*
- *pow*
- *min*
- *max*
- *clamp*
- *mix*
- *length*
- *distance*
- *normalize*
- *dot*
- *cross*

Many of the built-in functions take either scalars or vectors as arguments. For vector arguments the function is applied component-wise and the resulting vector is returned.

abs

```
abs(x : Number) : Number
abs(x : vec2) : vec2
abs(x : vec3) : vec3
abs(x : vec4) : vec4
```

Returns the absolute value of *x*.

```
{
    "show" : "abs(${temperature}) > 20.0"
}
```

sqrt

```
sqrt(x : Number) : Number
sqrt(x : vec2) : vec2
sqrt(x : vec3) : vec3
sqrt(x : vec4) : vec4
```

Returns the square root of *x* when `x >= 0`. Returns *NaN* when `x < 0`.

```
{
    "color" : {
        "conditions" : [
            ["${temperature} >= 0.5", "color('#00FFFF')"],
            ["${temperature} >= 0.0", "color('#FF00FF')"]
        ]
    }
}
```

cos

```
cos(angle : Number) : Number
cos(angle : vec2) : vec2
cos(angle : vec3) : vec3
cos(angle : vec4) : vec4
```

Returns the cosine of *angle* in radians.

```
{
    "show" : "cos(${Angle}) > 0.0"
}
```

sin

```
sin(angle : Number) : Number
sin(angle : vec2) : vec2
sin(angle : vec3) : vec3
sin(angle : vec4) : vec4
```

Returns the sine of *angle* in radians.

```
{
    "show" : "sin(${Angle}) > 0.0"
}
```

tan

```
tan(angle : Number) : Number
tan(angle : vec2) : vec2
tan(angle : vec3) : vec3
tan(angle : vec4) : vec4
```

Returns the tangent of *angle* in radians.

```
{
    "show" : "tan(${Angle}) > 0.0"
}
```

acos

```
acos(angle : Number) : Number
acos(angle : vec2) : vec2
acos(angle : vec3) : vec3
acos(angle : vec4) : vec4
```

Returns the arccosine of *angle* in radians.

```
{
    "show" : "acos(${Angle}) > 0.0"
}
```

asin

```
asin(angle : Number) : Number
asin(angle : vec2) : vec2
asin(angle : vec3) : vec3
asin(angle : vec4) : vec4
```

Returns the arcsine of *angle* in radians.

```
{
    "show" : "asin(${Angle}) > 0.0"
}
```

atan

```
atan(angle : Number) : Number
atan(angle : vec2) : vec2
atan(angle : vec3) : vec3
atan(angle : vec4) : vec4
```

Returns the arctangent of *angle* in radians.

```
{
    "show" : "atan(${Angle}) > 0.0"
}
```

atan2

```
atan2(y : Number, x : Number) : Number
atan2(y : vec2, x : vec2) : vec2
atan2(y : vec3, x : vec3) : vec3
atan2(y : vec4, x : vec4) : vec4
```

Returns the arctangent of the quotient of *y* and *x*.

```
{
    "show" : "atan2(${GridY}, ${GridX}) > 0.0"
}
```

radians

```
radians(angle : Number) : Number
radians(angle : vec2) : vec2
radians(angle : vec3) : vec3
radians(angle : vec4) : vec4
```

Converts *angle* from degrees to radians.

```
{
    "show" : "radians(${Angle}) > 0.5"
}
```

degrees

```
degrees(angle : Number) : Number
degrees(angle : vec2) : vec2
degrees(angle : vec3) : vec3
degrees(angle : vec4) : vec4
```

Converts *angle* from radians to degrees.

```
{
    "show" : "degrees(${Angle}) > 45.0"
}
```

sign

```
sign(x : Number) : Number
sign(x : vec2) : vec2
sign(x : vec3) : vec3
sign(x : vec4) : vec4
```

Returns 1.0 when *x* is positive, 0.0 when *x* is zero, and -1.0 when *x* is negative.

```
{
    "show" : "sign(${Temperature}) * sign(${Velocity}) === 1.0"
}
```

floor

```
floor(x : Number) : Number
floor(x : vec2) : vec2
floor(x : vec3) : vec3
floor(x : vec4) : vec4
```

Returns the nearest integer less than or equal to *x*.

```
{
    "show" : "floor(${Position}) === 0"
}
```

ceil

```
ceil(x : Number) : Number
ceil(x : vec2) : vec2
ceil(x : vec3) : vec3
ceil(x : vec4) : vec4
```

Returns the nearest integer greater than or equal to *x*.

```
{
    "show" : "ceil(${Position}) === 1"
}
```

round

```
round(x : Number) : Number
round(x : vec2) : vec2
round(x : vec3) : vec3
round(x : vec4) : vec4
```

Returns the nearest integer to *x*. A number with a fraction of 0.5 will round in an implementation-defined direction.

```
{
    "show" : "round(${Position}) === 1"
}
```

exp

```
exp(x : Number) : Number
exp(x : vec2) : vec2
exp(x : vec3) : vec3
exp(x : vec4) : vec4
```

Returns *e* to the power of *x*, where *e* is Euler's constant, approximately *2.71828*.

```
{
    "show" : "exp(${Density}) > 1.0"
}
```

log

```
log(x : Number) : Number
log(x : vec2) : vec2
log(x : vec3) : vec3
log(x : vec4) : vec4
```

Returns the natural logarithm (base *e*) of *x*.

```
{
    "show" : "log(${Density}) > 1.0"
}
```

exp2

```
exp2(x : Number) : Number
exp2(x : vec2) : vec2
exp2(x : vec3) : vec3
exp2(x : vec4) : vec4
```

Returns 2 to the power of *x*.

```
{
    "show" : "exp2(${Density}) > 1.0"
}
```

log2

```
log2(x : Number) : Number
log2(x : vec2) : vec2
log2(x : vec3) : vec3
log2(x : vec4) : vec4
```

Returns the base 2 logarithm of *x*.

```
{
    "show" : "log2(${Density}) > 1.0"
}
```

fract

```
fract(x : Number) : Number
fract(x : vec2) : vec2
fract(x : vec3) : vec3
fract(x : vec4) : vec4
```

Returns the fractional part of *x*. Equivalent to *x - floor(x)*.

```
{
    "color" : "color() * fract(${Density})"
}
```

pow

```
pow(base : Number, exponent : Number) : Number
pow(base : vec2, exponent : vec2) : vec2
pow(base : vec3, exponent : vec3) : vec3
pow(base : vec4, exponent : vec4) : vec4
```

Returns *base* raised to the power of *exponent*.

```
{
    "show" : "pow(${Density}, ${Temperature}) > 1.0"
}
```

min

```
min(x : Number, y : Number) : Number
min(x : vec2, y : vec2) : vec2
min(x : vec3, y : vec3) : vec3
min(x : vec4, y : vec4) : vec4

min(x : Number, y : Number) : Number
min(x : vec2, y : Number) : vec2
min(x : vec3, y : Number) : vec3
min(x : vec4, y : Number) : vec4
```

Returns the smaller of *x* and *y*.

```
{
    "show" : "min(${Width}, ${Height}) > 10.0"
}
```

max

```
max(x : Number, y : Number) : Number
max(x : vec2, y : vec2) : vec2
max(x : vec3, y : vec3) : vec3
max(x : vec4, y : vec4) : vec4
max(x : Number, y : Number) : Number
max(x : vec2, y : Number) : vec2
max(x : vec3, y : Number) : vec3
max(x : vec4, y : Number) : vec4
```

Returns the larger of *x* and *y*.

```
{
    "show" : "max(${Width}, ${Height}) > 10.0"
}
```

clamp

```
clamp(x : Number,  min : Number, max : Number) : Number
clamp(x : vec2,  min : vec2, max : vec2) : vec2
clamp(x : vec3,  min : vec3, max : vec3) : vec3
clamp(x : vec4,  min : vec4, max : vec4) : vec4

clamp(x : Number,  min : Number, max : Number) : Number
clamp(x : vec2,  min : Number, max : Number) : vec2
clamp(x : vec3,  min : Number, max : Number) : vec3
clamp(x : vec4,  min : Number, max : Number) : vec4
```

Constrains *x* to lie between *min* and *max*.

```
{
    "color" : "color() * clamp(${temperature}, 0.1, 0.2)"
}
```

mix

```
mix(x : Number,  y : Number, a : Number) : Number
mix(x : vec2,  y : vec2, a : vec2) : vec2
mix(x : vec3,  y : vec3, a : vec3) : vec3
mix(x : vec4,  y : vec4, a : vec4) : vec4

mix(x : Number,  y : Number, a : Number) : Number
mix(x : vec2,  y : vec2, a : Number) : vec2
mix(x : vec3,  y : vec3, a : Number) : vec3
mix(x : vec4,  y : vec4, a : Number) : vec4
```

Computes the linear interpolation of *x* and *y*.

```
{
    "show" : "mix(20.0, ${Angle}, 0.5) > 25.0"
}
```

length

```
length(x : Number) : Number
length(x : vec2) : vec2
length(x : vec3) : vec3
length(x : vec4) : vec4
```

Computes the length of vector *x*, i.e., the square root of the sum of the squared components. If *x* is a number, `length` returns *x*.

```
{
    "show" : "length(${Dimensions}) > 10.0"
}
```

distance

```
distance(x : Number, y : Number) : Number
distance(x : vec2, y : vec2) : vec2
distance(x : vec3, y : vec3) : vec3
distance(x : vec4, y : vec4) : vec4
```

Computes the distance between two points *x* and *y*, i.e., `length(x - y)`.

```
{
    "show" : "distance(${BottomRight}, ${UpperLeft}) > 50.0"
}
```

normalize

```
normalize(x : Number) : Number
normalize(x : vec2) : vec2
normalize(x : vec3) : vec3
normalize(x : vec4) : vec4
```

Returns a vector with length 1.0 that is parallel to *x*. When *x* is a number, `normalize` returns 1.0.

```
{
    "show" : "normalize(${RightVector}, ${UpVector}) > 0.5"
}
```

dot

```
dot(x : Number, y : Number) : Number
dot(x : vec2, y : vec2) : vec2
dot(x : vec3, y : vec3) : vec3
dot(x : vec4, y : vec4) : vec4
```

Computes the dot product of *x* and *y*.

```
{
    "show" : "dot(${RightVector}, ${UpVector}) > 0.5"
}
```

cross

```
cross(x : vec3, y : vec3) : vec3
```

Computes the cross product of *x* and *y*. This function only accepts `vec3` arguments.

```
{
    "color" : "vec4(cross(${RightVector}, ${UpVector}), 1.0)"
}
```

6.4.11 Notes

Comments are not supported.

6.5 Point Cloud

A *Point Cloud* is a collection of points that may be styled like other features. In addition to evaluating a point's `color` and `show` properties, a Point Cloud style may evaluate `pointSize`, or the size of each point in pixels. The default `pointSize` is `1.0`.

```
{
    "color" : "color('red')",
    "pointSize" : "${Temperature} * 0.5"
}
```

Implementations may clamp the evaluated `pointSize` to the system's supported point size range. For example, WebGL renderers may query `ALIASED_POINT_SIZE_RANGE` to get the system limits when rendering with `POINTS`. A `pointSize` of `1.0` must be supported.

Point Cloud styles may also reference semantics from the *Feature Table* including position, color, and normal to allow for more flexible styling of the source data. * `${POSITION}` is a `vec3` storing the xyz Cartesian coordinates of the point before the `RTC_CENTER` and tile transform are applied. When the positions are quantized, `${POSITION}` refers to the position after the `QUANTIZED_VOLUME_SCALE` is applied, but before `QUANTIZED_VOLUME_OFFSET` is applied. * `${POSITION_ABSOLUTE}` is a `vec3` storing the xyz Cartesian coordinates of the point after the `RTC_CENTER` and tile transform are applied. When the positions are quantized, `${POSITION_ABSOLUTE}` refers to the position after the `QUANTIZED_VOLUME_SCALE`, `QUANTIZED_VOLUME_OFFSET`, and tile transform are applied. * `${COLOR}` evaluates to a `Color` storing the rgba color of the point. When the Feature Table's color semantic is `RGB` or `RGB565`, `${COLOR}.alpha` is `1.0`. If no color semantic is defined, `${COLOR}` evaluates to the application-specific default color. * `${NORMAL}` is a `vec3` storing the normal, in Cartesian coordinates, of the point before the tile transform is applied. When normals are oct-encoded, `${NORMAL}` refers to the decoded normal. If no normal semantic is defined in the Feature Table, `${NORMAL}` evaluates to `undefined`.

For example:

```
{
    "color" : "${COLOR} * color('red')'",
    "show" : "${POSITION}.x > 0.5",
    "pointSize" : "${NORMAL}.x > 0 ? 2 : 1"
}
```

Implementation Note: Point cloud styling engines may often use a shader (GLSL) implementation, however some features of the expression language are not possible in pure a GLSL implementation. Some of these features include: * Evaluation of `isNan` and `isFinite` (GLSL 2.0+ supports `isnan` and `isinf` for these functions respectively) * The types `null` and `undefined` * Strings, including accessing object properties (`color()['r']`) and batch table values * Regular expressions * Arrays of lengths other than 2, 3, or 4 * Mismatched type comparisons (e.g. `1.0 === false`) * Array index out of bounds

6.6 File extension and MIME type

Tileset styles use the `.json` extension and the *application/json* mime type.

7 License

Some parts of this Specification are purely informative and do not define requirements necessary for compliance and so are outside the Scope of this Specification. These parts of the Specification are marked as being non-normative, or identified as **Implementation Notes**.